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DESIGNING WEARABLE INTERFACES FOR BLIND PEOPLE

Fábio Alexandre Aleluia dos Santos

DISSERTAÇÃO

MESTRADO EM ENGENHARIA INFORMÁTICA
Especialização em Arquitectura, Sistemas e Redes de Computadores

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To my parents.

Resumo

Hoje em dia os dispositivos com ecrã táctil, estão cada vez mais onipresentes. Até recentemente, a maioria dos ecrãs sensíveis ao toque forneciam poucos recursos de acessibilidade para deficientes visuais, deixando-os inutilizáveis. Sendo uma tecnologia tão presente no nosso quotidiano, como em telemóveis e tablets. Estes dispositivos são cada vez mais essenciais para a nossa vida, uma vez que, guardam muita informação pessoal, por exemplo, o pagamento através carteiras electrónicas. A falta de acessibilidade deste tipo de ecrãs devem-se ao facto de estas interfaces serem baseadas no que os utilizadores veem no ecrã e em tocar no conteúdo apresentado neste. Isso torna-se num grande problema quando uma pessoa deficiente visual tenta usar estas interfaces. No mercado existem algumas soluções mas são quase todas baseadas em retorno áudio. Esta solução não é a melhor quando se trata de informação pessoal que a pessoa deseja manter privada. Por exemplo quando um utilizador está num autocarro e recebe uma mensagem, esta é lida por um leitor de ecrã através das colunas do dispositivo. Esta solução é prejudicial para a privacidade do utilizador, pois todas a pessoas à sua volta irão ouvir o conteúdo da mensagem. Uma solução para este problema, poderá ser a utilização de vibração e de teclas físicas, que retiram a necessidade da utilização de leitores de ecrã. Contudo, para a navegação em menus a problemática mantém-se. Uma maneira de resolver este problema é através da utilização de uma interface baseada em gestos. Este tipo de interface é uma forma flexível e intuitiva de interação com este dispositivos. Até hoje, muitas abordagens têm vindo a apresentar soluções, no entanto não resolvem todos os pontos referidos. De uma maneira ou de outra estas abordagens terão de ser complementadas com outros dispositivos. Guerreiro e colegas (2012), apresentaram um protótipo que possibilita a leitura texto através de vibração, mas todo o impacto de uma utilização no dia a dia não é tido em conta. Um outro estudo realizado por Myung-Chul Cho (2002) apresenta um par de luvas para escrita codificada pelo alfabeto Braile, contudo não é testado para uma utilização com integração de uma componente de leitura, sem ser o retorno áudio. Dois outros estudos destacam-se, relativamente à utilização de gestos para navegação no dispositivo. Ruiz (2011), efetuou uma elicitação de gestos no ar, no entanto, eles não incluem pessoas invisuais no estudo, o que poderá levar à exclusão de tais utilizadores. Outro estudo apresentado por Kane (2011), inclui pessoas invisuais e destina-se a interações com gestos mas exigindo contacto físico com os ecrãs tácteis. A abordagem apresentada neste

estudo integra as melhores soluções apresentadas num único dispositivo. O nosso objectivo principal é tornar os dispositivos de telemóveis mais acessíveis a pessoas invisuais, de forma serem integrados no seu quotidiano. Para isso, desenvolvemos uma interface baseada num par de luvas. O utilizador pode usá-las e com elas ler e escrever mensagens e ainda fazer gestos para outras tarefas. Este par de luvas aproveita o conhecimento sobre Braille por parte dos utilizadores para ler e escrever informação textual. Para a característica de leitura instalámos seis motores de vibração nos dedos da luva, no dedo indicador, no dedo do meio e no dedo anelar, de ambas as mãos. Estes motores simulam a configuração das teclas de uma máquina de escrever Braille, por exemplo, a Perkins Brailler. Para a parte de escrita, instalámos botões de pressão na ponta destes mesmos dedos, sendo cada um representante de um ponto de uma célula de Braille. Para a detecção de gestos optámos por uma abordagem através de um acelerómetro. Este encontra-se colocado nas costas da mão da luva. Para uma melhor utilização a luva é composta por duas camadas, e desta forma é possível instalar todos os componente entre as duas camadas de tecido, permitindo ao utilizador calçar e descalçar as luvas sem se ter que preocupar com os componentes electrónicos. A construção das luvas assim como todos os testes realizados tiveram a participação de um grupo de pessoas invisuais, alunos e professores, da Fundação Raquel e Martin Sain.

Para avaliarmos o desempenho do nosso dispositivo por invisuais realizámos alguns teste de recepção (leitura) e de envio de mensagens (escrita). No teste de leitura foi realizado com um grupo apenas de pessoas invisuais. O teste consistiu em, receber letras em Braille, onde o utilizador replicava as vibrações sentidas, com os botões das luvas. Para isso avaliámos as taxas de reconhecimento de caracteres. Obtivemos uma média de 31 %, embora estes resultados sejam altamente dependentes das habilidades dos utilizadores.

No teste de escrita, foi pedido uma letra ao utilizador e este escrevia em braille utilizando as luvas. O desempenho nesta componente foi em média 74 % de taxa de precisão. A maioria dos erros durante este teste estão ligados a erros, onde a diferença entre a palavra inicial e a escrita pelo utilizador, é de apenas um dedo. Estes testes foram bastante reveladores, relativamente à possível utilização destas luvas por pessoas invisuais. Indicaram-nos que os utilizadores devem ser treinados previamente para serem maximizados os resultados, e que pode ser necessário um pouco de experiência com o dispositivo.

O reconhecimento de gestos permite ao utilizador executar várias tarefas com um smartphone, tais como, atender/rejeitar uma chamada e navegar em menus. Para avaliar que gestos os utilizadores invisuais e normovisuais sugerem para a execução de tarefas em smartphones, realizámos um estudo de elicitação. Este estudo consiste em pedir aos utilizadores que sugiram gestos para a realização de tarefas. Descobrimos que a maioria dos gestos inventados pelos participantes tendem a ser físicos, em contexto, discreto e simples, e que utilizam apenas um único eixo espacial. Concluímos também que existe um consenso, entre utilizadores, para todas as tarefas propostas. Além disso, o estudo

de elicitação revelou que as pessoas invisuais preferem gestos mais simples, opondo-se a uma preferência por gestos mais complexos por parte de pessoas normovisuais. Sendo este um dispositivo que necessita de treino para reconhecimento de gestos, procurámos saber qual o tipo de treino é mais indicado para a sua utilização. Com os resultados obtidos no estudo de elicitação, comparámos treinos dos utilizadores individuais, treinos entre as das populações (invisuais e normovisuais) e um treino com ambas as populações (global). Descobrimos que um treino personalizado, ou seja, feito pelo próprio utilizador, é muito mais eficaz que um treino da população e um treino global. O facto de o utilizador poder enviar e receber mensagens, sem estar dependente de vários dispositivos e/ou aplicações contorna, as tão levantadas, questões de privacidade. Com o mesmo dispositivo o utilizador pode, ainda, navegar nos menus do seu smartphone, através de gestos simples e intuitivos. Os nossos resultados sugerem que será possível a utilização de um dispositivo *wearable*, no seio da comunidade invisual. Com o crescimento exponencial do mercado *wearable* e o esforço que a comunidade académica está a colocar nas tecnologias de acessibilidade, ainda existe uma grande margem para melhorar. Com este projeto, espera-se que os dispositivos portáteis de apoio irão desempenhar um papel importante na integração social das pessoas com deficiência, criando com isto uma sociedade mais igualitária e justa.

Palavras-chave: *Wearable*, acessibilidade, invisuais, reconhecimento de gestos, ecrãs tácteis.

Abstract

Nowadays touch screens are ubiquitous, present in almost all modern devices. Most touch screens provide few accessibility features for blind people, leaving them partly unusable. There are some solutions, based on audio feedback, that help blind people to use touch screens in their daily tasks. The problem with those solutions raises privacy issues, since the content on screen is transmitted through the device speakers. Also, these screen readers make the interaction slow, and they are not easy to use. The main goal of this project is to develop a new wearable interface that allows blind people to interact with smartphones. We developed a pair of gloves that is capable to recognise mid-air gestures, and also allows the input and output of text. To evaluate the usability of input and output, we conducted a user study to assess character recognition and writing performance. Character recognition rates were highly user-dependent, and writing performance showed some problems, mostly related to one-finger issues. Then, we conducted an elicitation study to assess what type of gestures blind and sighted people suggest. Sighted people suggested more complex gestures, compared with blind people. However, all the gestures tend to be physical, in-context, discrete and simple, and use only a single axis. We also found that a training based on the user's gestures is better for recognition accuracy. Nevertheless, the input and output text components still require new approaches to improve users performance. Still, this wearable interface seems promising for simple actions that do not require cognitive load. Overall, our results suggest that we are on track to make possible blind people interact with mobile devices in daily life.

Keywords: Wearable, accessibility, blind, gesture recognition, touch screens.

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Chapter 1

Introduction

This dissertation aims to integrate, and adapt technologies with smartphones improve the usage by blind people. Our approach resorts to a wearable interfaces to allow blind users to interact with mobile devices. In this chapter we present our motivation regarding this subject. We also present, objectives, contributions, and an overview of the dissertation structure.

1.1 Motivation

Now a days touch screens are ubiquitous, present in almost all modern devices. They are part of an easy and universal interface. Touch screen devices present a wide range of possibilities in terms of possible interactions. This allowed the creation of devices based only on this type of interactions like smartphones. Furthermore, more applications for touch screen devices are used for general public services such as, the ticket system in public transportations. It is also possible to find this type of devices in our home, like in dishwasher machines that have touch panels instead of physical buttons. The increased use of touch screen devices have been replacing people at their jobs like in restaurants and supermarkets with the new self-service registers. Even at the automotive industry the implementation of LCDs and touch panels are more frequent, as an example, for the Tesla 2013 Model S[1] the company installed a 17-inch capacitive touchscreen as the control center. With these trends, we can assume that in the next years, touch user interfaces will become more ubiquitous.

With this massive utilization of touch screens it becomes important that everyone is able to access them. It is crucial that interfaces become usable by people with disabilities, including blind and visually impaired people. Until recently, most touch screens provided few accessibility features, leaving them partly unusable by blind people [12]. This happens because these interfaces are based on what users see on the screen and touching the content of the items. This becomes a major problem when a blind person tries to use

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[1] http://www.teslamotors.com/models

these interfaces. To address this problems several approaches were developed, most of them relying on audio feedback. A good example of this is Apple's VoiceOver, which allows them to know what is touched. Being capable of using it on the move is almost impossible. The problem is further aggravated when these devices do not have the same size, and even in mobile phones the sizes are different, varying the onscreen information. There have been studies in the past that aim to understand how blind people interact with these devices. In Guerreiro et al. [7], they explore how blind people interact with three different touch settings, touch phones with and without bezels, and a tablet. They found that the different screen sizes affect the target acquisition, being the smallest screen devices, the ones who gave the best results. They also stated that a simple addition of a physical border improves the users performance. Also, in Kane et al. [11], they tested differences between an audio-based interaction and a button-based system. Their results showed that the audio-based approach was faster then the button-based system, and users preferred the first technique. The urgency to make these devices more accessible led to the creation of several screen-based systems for blind people. As an example, NavTouch described in Guerreiro et al. [5], is a software that allows blind users to enter text on mobile devices such as smartphones. Other approaches of text entering on touch devices are BrailleTouch presented in Romero et al. [23] and HoliBraille in Nicolau et al. [16]. The description of these techniques and others can be found in Chapter 2. Although blind people use these approaches to interact with cell phones, all of these accessibility tools are still slow and demand dedicated attention. For example, audio feedback depends on the speed of the reading mechanism, and users must search every inch of the screen until they find what they want. Also, they are not private. Using these approaches in public expose their private information to everyone around them.

It is possible to use gesture-based shortcuts to perform several tasks. As an example, if a user wants to answer a call, the user has to locate the button and perform a swipe. Using a gesture-based shortcut, he can just pick up the phone. Studies like the ones presented in Section 2.3, aim the creation of gesture-based interfaces to allow blind people to interact with touch screen interfaces. Gestures are a flexible and intuitive form of input. Several devices were developed to detect hand gestures, like cameras, as an example the Kinect for Windows[2], and other projects that used sensors like an accelerometer embedded within a device for gesture detection, such as the one described in Ruiz et al. [24]. They presented a study were they used the accelerometer from a mobile device for gesture detection. Their results show that people are familiar with this type of interaction and that in the future it is possible to implement in touch devices. These types of interactions can become wearable, in other words, they are devices that can be embodied. There is a lack of understanding and exploration of the benefits of wearable devices and interactions for blind people.

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[2] http://www.microsoft.com/en-us/kinectforwindows/

1.2 Objectives

Based on these previous works, our goal is to study the performance and acceptance of wearable interfaces, to provide a faster and easier use of mobile applications. In particular, we focus on writing and reading text and creating shortcuts and actions through gestures. This can help them to perform tasks while on-the-go. To address our goal, we developed a pair of gloves that is capable to recognize mid-air gestures, and also input and output text to and from a smartphone. This process is based on three main tasks, described as:

1. *Field Research:* we compiled a user's requirement list. For this we collect all kinds of information about blind people when interacting with touch screen devices. We asked their opinion about the advantages and disadvantages of these devices; what are their needs when they try to use them; what they expect to find in these devices.

2. *Prototyping:* this is an iterative process. We built a prototype, we test it and with the results and comments we improved our prototype to test it again, and so on and so forth. The final result is the conceiving of a glove to be used by blind people to interact with mobile devices.

3. *Final Assessment:* This stage is focused on the usability and acceptability of the final product. To accomplish the goal of this stage we combined user tests with acceptance interviews. The product validation is important to achieve the main goal of designing a wearable interface.

1.3 Contributions

The wearable device developed in this dissertation can be use by blind people for day-to-day mobile tasks. The system was developed to perform main functions, such as, writing, reading and menu navigation. In future it is possible to be adapt for Braille learning, and modern forms of interaction. Our main contributions with this dissertation are:

- A hardware wearable prototype, that enables users to input and output text, make gestures to perform simple tasks.

- Knowledge about the conception and connection of this prototype.

- A set of gestures for common mobile tasks.

- Knowledge about the acceptance of wearable devices by blind people.

- Android interaction prototype for communication with the wearable device.

1.4 Structure of the document

This dissertation is organized in the following way:

- **Chapter 2 – Background**

  The background is divided into four sections. The first section describes the costume made braille devices and how they are being used to help blind people. In the second section we describe how braille is being used in mainstream devices, such as, smartphones and tablets. The third section is a review of what it was developed until now in wearable devices that uses braille as text input our output. The last section presents several elicitation studies that guide us in to the development of the mid-air gesture based interface.

- **Chapter 3 – A Wearable Interface for Blind People**

  Here we describe our system prototype. We described the system requirements and use case scenarios. We present and discuss the system design and architecture. Finally, we presented an integration of the system with an Android device.

- **Chapter 4 - Evaluating Wearable Braille I/O**

  In this chapter we present the results of the first study. For this, we first evaluate the acceptability of the prototype and then we evaluate the performance of reading and writing of the users with our prototype.

- **Chapter 5 - Preferences and Performance of Blind users in a gesture-based interface**

  Here we showed the second study, which was divided into two smallest studies. Here we aimed to know what type of gestures, sighted and blind people, and associate to specific tasks that they perform with a smartphone. Also, we present studies were we try to understand if there are differences between different methods of training the gesture recognizer.

- **Chapter 6 - Conclusion**

  This chapter presents a small conclusion, a discussion about the overall work, and future steps towards improving our prototypes.

Chapter 2

Background

Here we will do a short analysis of the existing work related with mobile interactions with blind people, wearable devices and gesture detection. This review will be divided into three sections. The first section, entitled ”Mobile Interfaces”, will review methods of interaction by blind people on touch devices. The second section, ”Wearable Interfaces”, will address several studies were wearable devices will be discussed. Finally, the third section, ”Gestural Interfaces”, will discuss gesture detection for gestural interfaces.

2.1 Mobile Interfaces

Mobile interfaces are part of mobile devices. To make them accessible to blind people they need to fulfill some requirements. Here we present some work already developed in this area.

To be possible these type of approaches and to test the efficiency in touch devices Guerreiro et al. [7] performed a study where blind people performed a low-level target acquisition test. This test includes three different devices, a normal smartphone, a smartphone with physical border and a tablet. Each participant performed the test with all three devices, randomly. With this test the authors could infer that the amount of targets, grid of 6 and 12 areas, on screen seems to have an impact in the errors rates. Some participants stated to have difficulties with the tablet, due to the size of the screen, since they have to cover a larger space. They verify that tapping on a corner have more efficiency. Also, the presence of physical borders showed a positive impact in the target acquisition. The results also showed high error rates for all settings, demonstrating that the conventional touch approach is not the most feasible for blind people. This study indicates that touch screens are typically inaccessible for blind people, however with specific features it is possible for them to interact with these devices.

Touch-based mobile devices lack tactile cues and are extremely visual demanding. For blind people who use this type of devices, they need to have a good spatial ability and memory. Besides this, several individual attributes are commonly forgotten, different levels of tactile sensibility, and verbal IQ. In Oliveira et al. [19] they presented a study with four methods of text-entry that are: Qwerty, that is base on a traditional keyboard with screen reading software; MultiTap, which presented a similar layout as the keypad-based devises with screen reading; The NavTouch[5] is a gesture-based approach, were the user can perform left, right, up and down gestures to navigate the alphabet, and BrailleType, the touch screen has six targets representing a braille cell.

Qwerty and MultiTap are more demanding concerning spatial ability due to the large number of on screen elements, and also faster compared with NavTouch[5] and BrailleType, however this two last methods are a less erroneous. Nevertheless, NavTouch[5] and BrailleType are more demanding on cognitive load, since the user has to keep track of what has written an what he wants to write next. The study also revealed that users with low sensitivity had more problems with multi touch interactions. The spatial ability, pressure sensitivity and verbal IQ as shown in this study have a big impact in the interaction with touch screens and particularly text-entry tasks.

Another type of interaction was presented in Kane et al. [11]. The authors developed Slide Rule, a set of audio-based multi-touch interaction that enable blind users to access touch screen applications. A user study was preformed with ten blind users. They were able to use Slide Rule, and at the same time use a button-based Pocket PC screen reader. Slide Rule provided a completely non-visual interface that reuse a touch screen as a “talking” touch-sensitive surface. This is based on a set of four gestures, one-finger scan to browse lists, a second-finger touch to select, a multi-directional flick gesture to perform additional actions, and an L-select gesture to browse hierarchical information. Slide Rule was faster than the Pocket PC getting a mean time for tasks of 11.69 seconds, while the screen reader have a mean time for completion of 12.79 seconds. Although users were faster with Slide Rule, the errors rate was higher, whereas, with the screen reader there was no errors. Their results show that Slide Rule was faster than the button-based system but more error prone resulting in a speed-accuracy tradeoff.

Another braille keyboard is BrailleTouch[23]. This technology explores the use of braille as a method of text input on touch screen mobile devices. So the main design goal is to produce an efficient text input system that fits on space-constrained mobile devices and can be effectively operated eyes-free and the system should be easy to learn. With these guidelines they create a braille soft keyboard prototype for iPod touch, iPhone and iPad. In the iPod/iPhone version the users hold the device with the screen facing away from them and then they place their fingers in a correspondent position to a standard braillewriter. When the user types a certain letter, BrailleTouch gives an audio feedback corresponding to the letter entered. In the iPad version the keyboard is a linear six-button layout that is comparable to the industry standard braille physical keyboards, such as the Perkins brailler. They implement an adaptive Braille keyboard.

Azenkot et al. [2] introduces a similar mobile application, the Perkinput text entry method. They also presented algorithms to detect which fingers touch the screen based on user-set reference points. In the end they present a study with eight participants with braille experience.

Perkinput uses two hands to enter a character. Users must tap with three fingers from each hand. If the screen is to small it is possible to use just one hand each time. If the user have two devices with small screen it is possible to use both to enter a character, using one hand in each device. They identify three possible error sources, hand repositioning, touch-point inconsistency and hand drift. To determine which fingers touched the screen, they compare the input touch points to the reference points set by the user.

These authors also compared the one-handed Perkinput with VoiceOver, a screen reader from Apple. Results showed that one-handed Perkinput was significantly faster, more accurate, and also showed a higher learning rate than VoiceOver. 7.26 WPM with one-handed Perkinput and 4.52 WPM with VoiceOver. Two-handed devices are faster than one-handed Perkinput, with an average speed of 20.4 WPM. In both methods the users improved over time.

Regarding text introduction, some work in the area of reading braille has been done, V-braille[9] is one example. Is presented as a new way to haptically represent braille characters on a standard mobile phone using the touch-screen and vibration. The authors said that with minimal training V-Braille can be used to read braille. Using Bluetooth with V-Braille is possible to connect to braille note-takers, increasing the number of possible applications. This application divides the screen into six parts, reproducing the six dots of a braille cell. When the user touches the screen, the phone vibrates if the area that was touched represents a raised dot. In this version they do not use multi-touch.

This authors started by asking users to read 10 random V-Braille characters. They recorded the amount of time the users took to read each once and then how long they took to read a short sentence of 21 characters. To read braille characters the average duration ranged between 4.2 and 26.6 seconds and was obtained a 90% accuracy rate. To read a small sentence, users took from 130 to 781 seconds.

There are other approaches that can be built, such as augmenting mobile devices. With this is possible to create a portable device that enables easier interactions. Next, we approach some of the work done related to augmented interfaces, that allow mobile interactions.

Subbu and Gnanaraj [27], introduces a design of a new device, the Unit-celled refreshable braille display(see Figure **??**), that will convert digital text into braille, giving the equivalent braille letter in the form of vibrations. This device will enable a visually impaired person to read messages on cell phones and/or emails. Despite the technological development, these people are unable to share messages through modern gadgets without help from normal people. Six DC vibrator motors replace the six dots of a braille cell. This device can be paired to the phone via Bluetooth. The device uses Bluetooth and then receives the data from the mobile device, which is shown out as output in the Unit-cell. This approach will help them to socialize and also collect information from the mobile device.

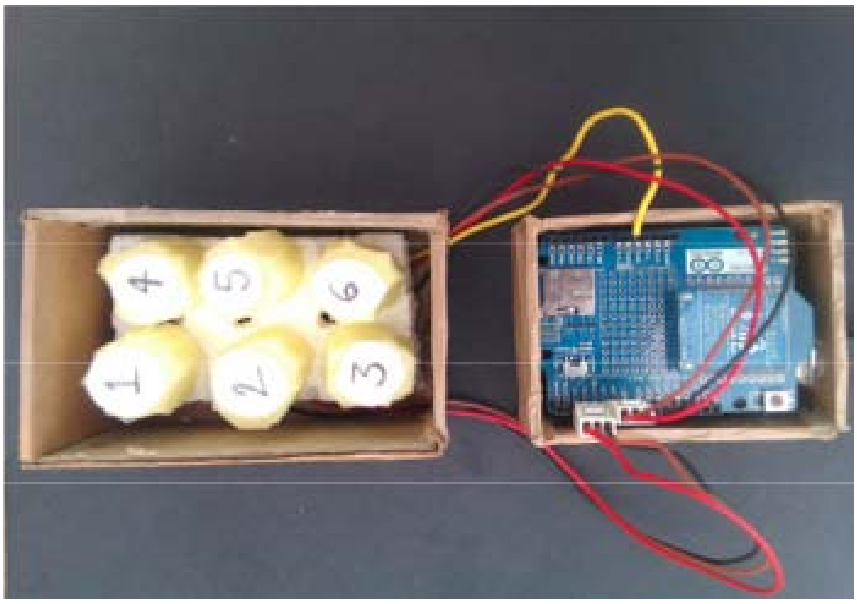

Figure 2.1: Unit-celled refreshable braille display[27].

The technology presented opens up new methods of interaction with a mobile device for blind users. In the field of computer access for blind users is comparable with the introduction of touch screens for sighted users, but in a more familiar interface.

Blind people have great difficulty in detect and correct errors when it comes to entering text in touch interfaces. HoliBraille [16], is a combination of input, through touch interactions, and output over multi-point vibrotactile for braille text entry in mobile devices. The HoliBraille combines this method with a BrailleTouch's usage setup, where the screen is facing away from the user and finger tracking techniques allow multi-point and single feedback on each finger. A preliminary study showed that using springs, the vibrations caused by motors, is not transmitted to other fingers, avoiding erroneous readings by the users. Six small vibration motors strategically secured by springs and a silicon case compose the final design. One extra feature presented is that the spring molded by themselves to different hands shapes, allowing a more comfortable position.

In order to assess the viability of the HoliBraille, the authors accomplished a study where two results emerged, the first showed that a single finger vibration is 100% accurate, The second one showed that most confusions rise between ring-index fingers and all three fingers chords, this specific test have a 82% accuracy.

All of these approaches are appropriate for the integration of blind people in our digital society. The main problem is that most of the text input methods presented require the handling by the users in an awkward way. Resulting in an uncomfortable experience.

2.2 Wearable Interfaces

Wearable gizmos are the next frontier in the world of technology. These devices increase and extend human capabilities. At the same time they preserve the privacy of users. They are light and portable, with a variety of features in a single device that provide a comfortable user experience.

UbiBraille[15] is a vibrotactile reading device that allows the users to read text, conserving their privacy. The UbiBraille is composed by six vibrotactile motors, which are used to emulate the traditional braille writing mechanism where chords of six fingers are used to code each character. Several tests showed that the best position, for the rings, was the middle of the fingers. They also presented also two user studies to assess character and word reading performance.

The first study presented was the character reading. Results showed that letters ”N”, ”O”, ”V”, ”Y”, and ”Z” are harder to recognize, and on average the accuracy is 82%. Half of the errors were due to 1-fingers issues. A second study is related to words reading. Participants heard an audio signal followed by stimuli that corresponding each character from the selected word. This study showed us that two seconds per character is enough, the longest durations showed very similar recognition rates. These tests show that participants take advantage of previous braille knowledge. Participants felt to be improving and with more training would be able to attain better performances.

Another possible way of reading braille through wearable device was presented in Ohtsuka et al. [18]. Body-Braille is a wearable system, which has been developed as a new communication channel for deaf-blind people using 6 micro vibration motors. This 6 micro vibration motors are used on the surface of the body. The device has several advantages, such as, any part of the body can be used to receive braille data and symbol information, and the users receive information passively. This device can be useful for blind users to study braille.

The Body-Braille system consists in a control device named “B-brll” and vibration motors. The main input device has eight switches. Six of them are used for braille character input, and the other two switches for auxiliary functions, such as spacing and/or shifting. The main output device is the six vibration motors, by which the braille information is transmitted. The most preferable parts of the body for reading this information are the arms and the back.

In Cho et al. [3] a pair of Braille-based chord gloves was proposed. Each glove has seven buttons. The buttons were mounted on the fingers of gloves and their chording methods resemble those of a braille keyboard. Three buttons at the fingertips of each glove correspond to braille dots. The others correspond to space bar, backspace and return or enter. The output of this embedded system is connected to LCD displaying character or number and LED displaying five braille cells. Since the proposed chord gloves use two hands to input some characters or numbers instead of using one hand. Visually impaired people who have used a braille keyboard can use the proposed chord gloves without a learning process.

Further a pair of wireless Braille-based chording gloves[1] was presented as an input device to use in a mobile working environment for visually impaired people. IrDA (Infrared Data Association) and RF (Radio Frequency) wireless modules were designed and implemented to make the proposed chording gloves wireless. The buttons were added to the fingertips and the chording method is similar to a braille keyboard. Six of them corresponds to each dot in a braille cell, the rest of the buttons preform combinations of chords, as an example, when a user presses one of this special buttons it simulates the press of three.

Experiments were performed with ten visually impaired perticipants who just start to learn braille. The authors asked them to enter different sentences during the training session. The participants gave their opinion about both, the gloves and the keyboard in the following parameters: portability, learnability, functionality, and overall satisfaction. Results showed that the proposed chording gloves have an input speed of 121.5 ± 29.8 BPM (braille code per minute) and error rate of (%) 5.2 ± 2.7. While a braille keyboard presented an input speed 135.9 ± 37 and error rate 2.8 ± 2.3.

Chording gloves have clear space advantages over an ordinary keyboard and other chording keyboards. It may take longer time for sighted people to learn the key map, but after that, the input speed of the proposed system will be almost as faster as normal input devices. But it is not the only option regarding this type of devices. Another devices not related with braille were developed.

An alternative eyes-free wearable interface for mobile phones is presented in Ye et al. [30]. To explore the impacts of such technology the authors conducted two studies. The first one was an on-line interview with sighted and blind people. They include both populations to compare in terms of current device usage. For the first one they proposed two scenarios, a wristband and a glasses-based device. In the wristband scenario, they asked the user to imagine a device that allows them to interact with a mobile phone, through gestures. The glasses-based scenario, they proposed a wearable device that can analyze the visual environment and communicate this information to the user. This study aims to understand how wearable interactions can be designed to fulfill the needs of a large portion of users. People think that the wristband device might be quicker, discreet, and safer. Glasses-based devices were also well accepted, mainly for navigation support, reading text and facial recognition.

In the second study, they developed a wristband that allows interacting with touch device. Participants said that the wristband was easy to use and required only brief training. They were positive about adopting a device with these features.

These findings showed that smartphones could be accessible to all. Specially blind people that have been excluded from recent technologies. Results regarding wearable interfaces showed that these could have a positive impact in the way that blind people use smartphones. But to use these types of interfaces with high acceptability, it is important to create a simple and easy way of using such devices. One simple way is using gestures that users understand and that they can memorize quickly, to do that a solid set of gestures is needed. In the next section we will explore this problematic.

2.3 Gestural Interfaces

Gestural interfaces are simple and practical to use, but some times they are not appropriate to general public, including blind and sighted people. To accomplish this it is necessary to create a set of gestures, that are consistent and easy to remember. Several groups have been developed prototypes to cover all these requirements, however some of them partially fail to include all of them.

WatchIt [20] is a simple gesture eyes-free bracelet that extends the interaction beyond the screen of the watch. In this paper the authors investigate the usability of the device in an eyes-free context. In this paper they also preformed a survey to understand how the general public see the utilization of wearable devices. Results of the survey showed that sixty percent of the participants were interested in this type of devices. The presented interface aims the usage of simple gestures like finger pointing. The pointing gesture was used to select an item in a list or as a shortcut. Sliding our scrolling consists in sliding the finger along the band, up and down.

Martins et al. [14] also developed a wearable gesture-based interface, which was created for gaming. The Gauntlet takes the form of an arm piece. This interface allows the manipulation of game-play elements. The prototype is a glove with a long sleeve, which comprises an accelerometer, a gyroscope, an RFID reader, a force sensor, and a vibration motor. The vibration motor was added to give haptic output to the user. During a public demonstration some opinions were taken into account. The Gauntlet is difficult to wear, tends to become hot, but is comfortable. Finally some users wished that the set of gestures were a bit wider.

Another two gesture-based interfaces are introduce by Rekimoto [21], the GestureWrist and GesturePad. Both approaches allow users to interact with nearby computers using gesture-based commands. The GestureWrist, is a wristband-type input device that recognizes hand gestures and forearm movements, and GesturePad is a sensing module that can be attached on the inside the clothes. GestureWrist uses two types of sensors, a capacitive accelerometer, and a tactile actuator. To recognize hand gestures uses a combination of transmitter and receiver electrodes that are attached inside the wristband. When a user moves the hand, the shape of the wrist changes which allows the device to detect the movement. When a gesture is recognized the device gives feedback to the user. The combination of both sensors allows several combinations of gestures. GesturePad tries to convert conventional cloth into interactive interfaces, is based in a layer of sensors that can be attached to the inside of clothes. To use this interface the user brings the finger close to the sensor and the sensor grid recognizes the finger position. This design tries to be as discrete as possible, so the social acceptance increases in the wearable's market.

Elicitation studies are also a reliable method to validate this type of devices. Kane et al. [12] used a study elicitation to compare how blind people and sighted people use touch screen gestures. In this gestures elicitation study they asked to ten blind and ten sighted people to suggested gestures to perform common computing tasks. The authors also did a performance study in which the same participants performed a set of reference gestures.

The participants suggested gestures that could be used to execute a set of computing commands. The gesture elicitation found that blind people have different gesture preferences than sighted people. They prefer gestures on the edges of the screen and gestures that involve tapping virtual buttons. For the second study users preformed specific gestures pre-defined by the authors. Results showed that there are significant differences in the speed, size, and shape of gestures performed by blind people versus the gestures performed by sighted people.

With this, the authors were able to present a set of directions for a future design of gesture-based interfaces. Edges and other landmarks should be favored, as well as reducing the demand for location accuracy, and reproduction of familiar spatial layouts.

Here we review two more elicitation studies, Ruiz et al. [24], and Wobbrock et al. [29]. In Ruiz et al. [24], they presented a guessability study that elicits end-user motion gestures to invoke commands on a smartphone device. They pretend to known about the best practices in motion gesture design. The authors asked to twenty participants to suggest motion gestures with a smartphone to preform a task. Overall they found that a major theme emerged, gestures should mimic normal use. All the participants evaluate the social acceptability of a gesture, by whether they believed if a bystander could interpret the intention of the gesture (or gestures that mimic gestures in the set) or not. If the bystander can interpret the gesture, this would have a higher socially acceptability.

In Wobbrock et al. [29], the authors developed an approach to designing tabletop gestures. For the study they asked to 20 participants to suggest gestures for 27 commands. Also, each participant saw the effect of a gesture and was asked to perform the gesture that they thought would cause that effect.

The authors found that participants preferred 1-hand gestures for a majority of the asked tests. They also found that the agreement for 1-hand gestures was stronger, and that some 2-hand gestures had a good agreement that complements the weakest 1-hand gestures. The authors stated that in opposite tasks, participants suggested similar gesture but on reverse directions.

After this, authors were able to conceive a user-defined gesture set based on the agreement that participants exhibited. This user-defined set has properties that make it a good example for future tabletop systems, as they are easy to recognize, are consistent, reversible, and versatile. Authors compared a preconceived gestures set with the user-defined gestures, and they only found a similarity of 43.5%. This suggests that elicitations studies are important and reliable than a preconceived set.

Guerreiro et al. [6] presented a body space based approach to improve mobile device interaction and on the move performance. The main idea was the validation of mnemonical body shortcuts concept as a new mobile interaction mechanism. The results showed that body-based gestures are suitable for mobile interaction and efficient. To overcome mobile interactions issues and on-the-move mobile device interaction, a gestural input technique was proposed. As the body limits the number of possible associations, they used gestures with a button to recall different actions for the same performed gesture. For the gesture detections they used two approaches. The first was an RFID-based prototype able to associate body parts (through sticker tags) with any given mobile device shortcut. The second was an accelerometer-based approach, for that they used a tri-axial accelerometer. The authors asked for the five most frequently tasks effectuated with their mobile phones, and associate them with a body part, and a mobile device key. The results showed that writing a text was mostly related with hands, whereas answering a call was associated with a ear and moth. Then the users were asked to access the previously selected applications, following both body and key shortcuts. These results showed that gestural mnemonics had better results. For the accelerometer prototype users preformed 5 gestures, 4 times each. The results showed higher recognitions rates. Suggesting that this is the best approach.

Headon and Coulouris [8] described a wearable system based on RFID, this system allows users to preform simple commands and input operations through gestures. This describes a preliminary evaluation of the system's usability. Positioning the right arm relative to the body performs the gestures. A reader antenna is worn on the user's wrist and passive RFID tags are worn on the body, for example on a shirt. Gestures are recognized by the location of the reader antenna relative to a tag located in a body part. Sequences of these static gestures produce dynamic gestures. Tags can be placed anywhere to define new regions. A usability test was preformed to evaluate the accuracy of absolute and relative tag selection while walking. In the absolute selection experiment the user return his right arm to the side prior to each tag selection. In the relative case the user maintains wrist close to the tag after preforming the gesture. The usability tests revealed an error rate of 11.1% and 1.72 seconds of mean time for the absolute test, For the relative test got 12.5% for error rate and 1.17 seconds of mean time. The implementation exhibits good accuracy while walking and it is expected to increase with user training. The authors argue that close proximity sensing using RFID is robust to changes in environment conditions, and that complex algorithms are not required.

Another command system that uses the tilt of the device as an input is presented by Rekimoto [22]. The authors said that with the use of tilt and buttons it is possible to build several interaction techniques. In this paper they explored the utilization of tilts, through sensing the rotations of the device. This approach uses a gyroscope since it is much more precise than an accelerometer in this case. To evaluate the system usability they preformed an informal evaluation that suggested that users could control the tilt precisely if visual feedback was provided adequately. Results showed that users were able to control the menu selection with only a 2-degree tilt. This feature is particularly useful for very small electronic devices. The system was also used for map browsing and manipulation of 3D objects.

gRmobile is a touch and accelerometer command system for gesture recognition presented by Joselli and Clua [10]. They developed a novel framework for gesture recognition. This translates in a system that need train and that saves all gestures. The results showed that with a database with ten gestures, see Figure 2.2, the proposed system could be used in real-time applications such as games. In order to test the accuracy of the recognition, the authors defined a set of ten different gestures for mid-air gestures and ten for touch gestures.

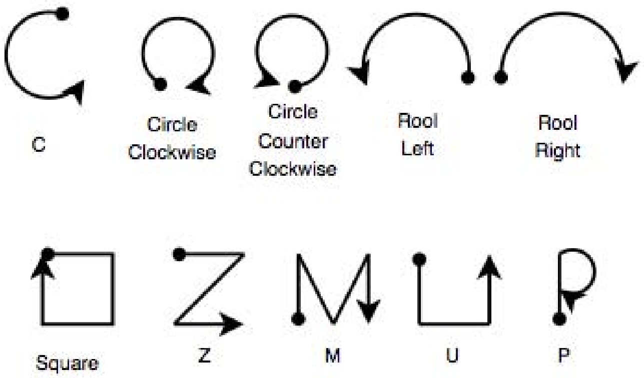

Figure 2.2: Set of gestures proposed in Joselli and Clua [10]

Results showed that it is possible to use light frameworks for gesture recognition, with good recognition rates, using the mobile phones limited hardware.

Hand gestures are a powerful human-to-human communication modality, in Niezen and Hancke [17] the authors presented a gesture recognition for mobile phones. They developed an accelerometer-based gesture recognition technique that can be implemented on a mobile phone through hidden Markov models. In this paper they used 8 gestures, see Figure 2.3.

When the user starts to move the phone, the application records the gesture until the phone stops moving. For the recognition process, the user selects the Recognize command from the pop-up menu. When the device stops moving the application displays the recognized. They used haptic feedback using vibrotactile capabilities of the mobile phone

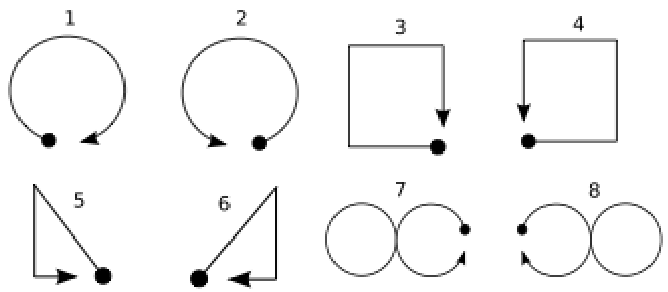

Figure 2.3: Set of gestures proposed in Niezen and Hancke [17]

when a gesture is recognized. This test showed a recognition rate of 96.25 %.

Another accelerometer command system is presented by Choi et al. [4]. Here they proposed a gesture-based interaction method using a tri-axis accelerometer. In this approach the mobile phone was able to recognize numbers drawn in the air from 1 to 9, and five symbols written in the air. The shaking detection methods showed that gesture-based interaction could be used as input methods of games and musical instrument applications. In gesture-to-sound generation, a user draws ’O’ or ’X’. Then the corresponding pre-recorded sound is played. For message deletion, they used the movement of shaking several times. On usability tests the presented system show an average of recognition rate of 97.01 %. The authors stated that it is possible to archive higher recognition rate by using trajectory estimation method for a large gesture set.

Most of the reviewed work is directed to sighted people, however, not always they participate in these studies. Now is important to understand if blind people can interact through gestures in the same way as sighted people. Our approach tackles this need. For the developed work in this thesis we try to understand and create a set of gestures that both, blind and sighted people can use. Using the best of solutions reviewed here we aim to create a wearable interface that allows reading, writing and gestural interactions with touch screen devices.

2.4 Discussion

Here we reviewed part of the work done, in software and hardware, that allow blind people to access mobile devices. Some of those, mobile and wearable interfaces, extend human capabilities, working as a prosthetic device. Normally, they are used in combination with mobile devices. We also reviewed gestural interfaces, which are simple and practical, and were developed based on body shortcuts. They allow the performance of several tasks in mobile devices.

All of them showed positive results, however, they still fall short in expectations. The mobile interfaces fail in the preservation of the privacy, falling constantly in audio feedback. Also, they demand high cognitive load, causing the user to have to devote, his attention, exclusively to the task he is doing. As well as wearable interfaces, that has the same problem regarding audio feedback. Almost all the interfaces reviewed here need an audio feedback feature, which becomes a problem in terms of privacy. As we could show, little is known about the acceptability of blind people with respect to this theme. Despite the good results about gestural interfaces, few of these studies included blind people in their usability tests. All these problems, launch the need to develop a user interface that meets all the requirements that the reviewed literature fail to implement.

Chapter 3

A Wearable Interface for Blind People

In this chapter, we present a wearable interface for blind people. Our design is based on a pair of gloves that allows blind users to interact with their smartphone. Here we describe how our prototype was developed, and all the design decisions that were made. This prototype will allow reading and writing in braille, and mid-air gestures interactions.

3.1 Use Case Scenarios

In this section, possible use case scenarios relative to the usage of the two interaction possibilities are presented. The first one represents the read-and-write functionality. The second one regards the gesture recognition feature.

3.1.1 Scenario 1

Paul, a 56 years old is blind from birth and lives in Lisbon. One of his favorite activities is to travel by public transportation. Beyond this occupation, he also likes to exchange messages with friends and family with his smartphone. Once he uses very often, public transports, he is faced with the loss of privacy when receiving messages, since he uses a screen reader. Paul does not use headphones because he does not want to lose awareness of the surrounding environment.

His daughter Amanda heard of some new gloves that use vibrations for text reading through Braille chords, and writing text through touch sensors. So she decides to offer this pair of gloves to his father.

One day of autumn, Paul decided to take a bus to go to his favorite garden. On his way there, he receives a message from his daughter, asking if he was going to dinner at her place. At that moment, Paul heard the message tone. Performs a gesture, and starts receiving braille chords through vibrations. With this process, Paul gets to know the content of the message. To reply to the message, he makes another gesture, and writes the answer, in his legs, using Braille. The sensors send to his mobile phone the captured signals and convert it to text. When he finishes writing the message, he performs the send gesture.

At the end, Paul is very pleased that he could receive a message and reply, maintaining his privacy and without disturbing the people around him.

3.1.2 Scenario 2

James, a 33 years old man, blind since age 5, lives in Porto and is a musician. Apart from composing, he likes to listen to music whenever he can. On his birthday, his girlfriend Lucy offered him a pair of gloves that let him control his mobile phone through mid-air gestures.

Thrilled with this gift, he quickly tried these gloves. For that, he first has to calibrate the recognizer to be as accurate as possible. Then he used the navigation gestures to go to his playlist and started listening to music. To further explore this new form of interaction he began to pass the songs forward and back, using the ”Next” and ”Previous” gestures.

James was so pleased that reinforced that he could even answer and hang-up calls while on-the-move, without having to take his mobile phone from his pocket.

3.2 System Requirements

The main goal of this project is to build a wearable and mobile interface for smartphones that allows blind people to perform simple tasks, and use it through mid-air gestures. Taking into account this, and the background literature we compiled functional and non-functional requirements, from informal interviews and literature review.

3.2.1 Functional Requirements

In this section it is presented the functional requirements for the system. The functional requirements address what the system does. They are the type of behavior the designer want the system to perform. These requirements are as follows:

1. The system should be able to transform text into Braille chords.
2. The system should convert Braille chords into text.
3. The system must be able to detect mid-air gestures.
4. The interface need to give feedback when being used.
5. The system should be comfortable.

3.2.2 Non-Functional Requirements

In this section, we present the non-functional requirements of the system. The non-functional requirements define restrictions on the types of solutions that will meet the functional requirements.

1. The conversion between text and braille chords must be instantaneous.
2. The gesture recognition must be made in less than half a second.
3. The button press feedback should be provided at the same time the user is pressing it.
4. The gloves should be made in a fabric that suits the user hand.
5. The fabric used should not be too hot, to be used in the summer.

3.3 System Design

The present section will present all the necessary considerations to design a system that aims to help blind people to interact whit their smartphones and personal computers in a easy and fast way. Due to new wearable technologies, it is possible to build multiple forms of portable communication. These types of wearable prototypes were made possible due to Arduino[1], that transformed the prototyping world with a more cheap and accessible way of prototyping, reaching to more people around the world. This has an Atmel AVR controller, and support for input and output data in order to ease the planning and prototyping. In terms of programming, offers a language based on C / C ++. The purpose of these devices is the creation of low-cost hardware prototypes, allowing its expansion with the components that you want and program them. They can be used independently or connected to a computer through a USB cable. We chose Arduino Mega ADK[2] as comprising one of the best price-quality relationship also allows the connection to Android devices. The specifications for the Arduino Mega ADK is presented in Table 3.1.

Furthermore the wearable technologies are widely accepted in our society, i.e. are considered normal in the daily basis for more and more people. This social acceptance is important to prevent that disabled people, are stigmatized when using this type of devices. In these devices are included new smartwatches, intelligent glasses and wearable cameras. We used Arduino, to develop a prototype that allows a user to write and read braille chords, and also capture gestures made by him. This Arduino device is installed in a pair of gloves that were specifically made for this prototype.

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[1] Arduino web site: http://arduino.cc/

[2] Arduino Mega ADK web site: http://arduino.cc/en/Main/ArduinoBoardMegaADK?from=Main.ArduinoBoardADK

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
USB Host Chip	MAX3421E

Table 3.1: Table with Arduino Mega ADK Specifications.

As for the reading part, we chose to use six vibration motors to silently transmit Braille chords from a mobile phone or personal computer. For the writing part, we used prototyping buttons, and for the gesture detection we used an accelerometer. The main focus of this work is the acceptance and performance of users, using this type of interface. During the process of conception of these gloves many design options were taken.

3.3.1 Emplacement of the Equipment

The idea behind this project is to wear a Braille typing machine, a braille reader, and an accelerometer. The problematic of emplacement all this equipment, in such a small space, is addressed in this section. The emplacement can influence the outcome of the results having the power to dictate if the interface will succeed or if it will fail.

3.3.1.1 Gloves

The conception of the glove itself proved to be a challenge bigger than it was expected. First we focused on the loss of sensation by users, latex gloves were the first idea, but they were too thin and broke to easily. The second option was Lycra gloves. They are flexible and thin but do not break so easily. The problem with this material is, that normally, in the market they have only one layer, this makes impossible to incorporate all sensors, without being always falling, breaking, and tangling wires.

So the option was to make the gloves by hand with the specifications that were more suitable for the prototype. For that, we bought Lycra and make two layered gloves. In this way we were able to install all the necessary equipment between the layers, making it easier to wear them. It is possible to see the costume made gloves in Figure 3.1.

Using gloves there is no alternative in where to place the components. For the vibrating components the first idea was seen in Nicolau et al. [15]. Using this idea we

(a) Front end of the gloves **(b)** Back end of the gloves

Figure 3.1: Figure with the final product of the costume made gloves.

removed the rings and placed them between the two layers of fabric. Initially, the vibration intensity was equal in all motors. Due to vibration damping problems, and sensitivity differences between the fingers used, we had to change the vibration intensity depending on the finger that the motor was placed. Overall we divided by half the intensity in all fingers. After a preliminary test we found that the middle finger has less sensibility than the index, and ring fingers. So we decreased the vibration intensity even more on index and ring fingers.

The reason for the motors being in that position, in the middle phalanges, and not in the proximal phalangesis due to the proximity of the motors, the vibration propagation inhibits the user to distinguish the vibrations. As closer to the fingertips, more vibration damping is achieved.

The position of the writing buttons was straightforward. We placed the button on the fingertips. With this position we wanted to emulate a brailler machine but instead of being on the table, the buttons are in the gloves. This position allows the user to write everywhere, on a table, legs, walls, and even in its own hands. The accelerometer was initially sewed in the back of the hand, depending if the user is right-handed or left-handed, the sensor can be sewed in the gloves in the right or left hand. For the usability studies that involve the sensor, for practicability, it was sewed on a Velcro stripe to be easily strapped in and out.

3.3.2 Hardware

The diagram presented in Figure 3.2, represents a scheme of all the connections that are necessary to connect all components of the system. The scheme presents a breadboard instead of a pair of gloves to be more understandable. The components of the right glove are marked with the right rectangle with the legend ”Right Hand”, on the diagram, and the left glove materials on the ”Left Hand” rectangle. The red button can be used as a space in ”writing mode” or ”start recognition” on gesture detection mode. The green button it is only used as train gesture activation. The rest of the push buttons are used to make braille chords. Those buttons were installed, as previous explained on the fingertips. The red and green buttons were placed on the thumbs.

All these components were connected at 5V. The vibration motors were connected to the analog ports to be possible to regulate the intensity of the vibration, and the accelerometer was connected to a 3.3V port with both connectors, VCC and CS. The Accelerometer is also connected by SDA and SCL to their respective ports on the Arduino board, connections 20 and 21.

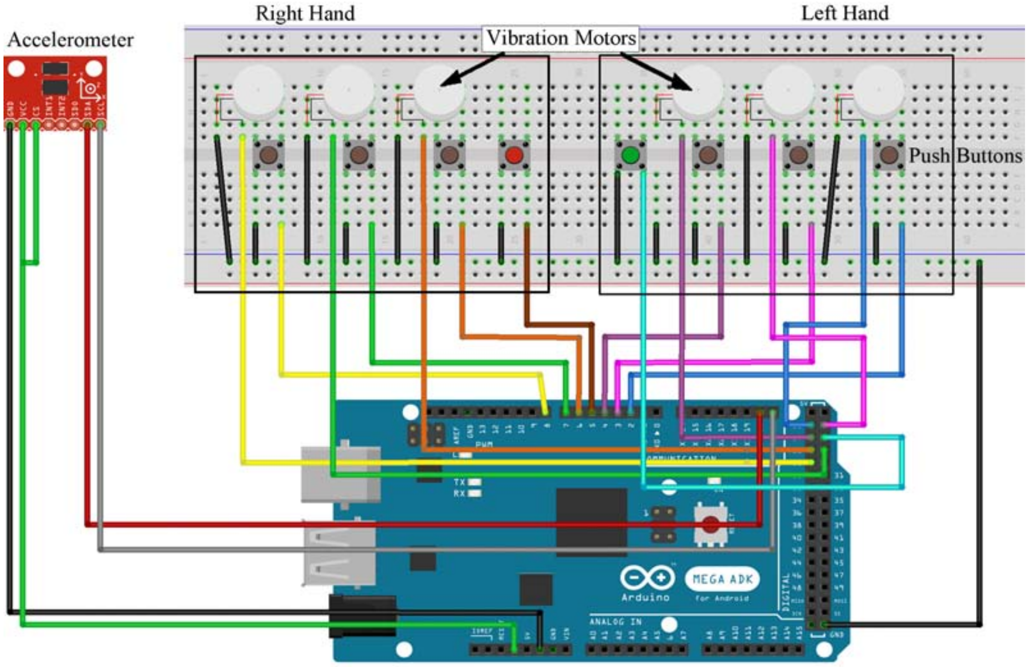


Figure 3.2: Schematic view of the system with the components connections of the gloves. The presented scheme was done with the help of the Fritzing software. All the black connections represent the ground connections.

3.3.3 Software

In terms of software development during this project, it was developed a program in Java that allows the communication with the gloves. Basically, all the text written with the gloves will appear on the computer prompt and all the text written on the console will be transmitted to the gloves. This software component is also responsible to manage the gesture recognizer.

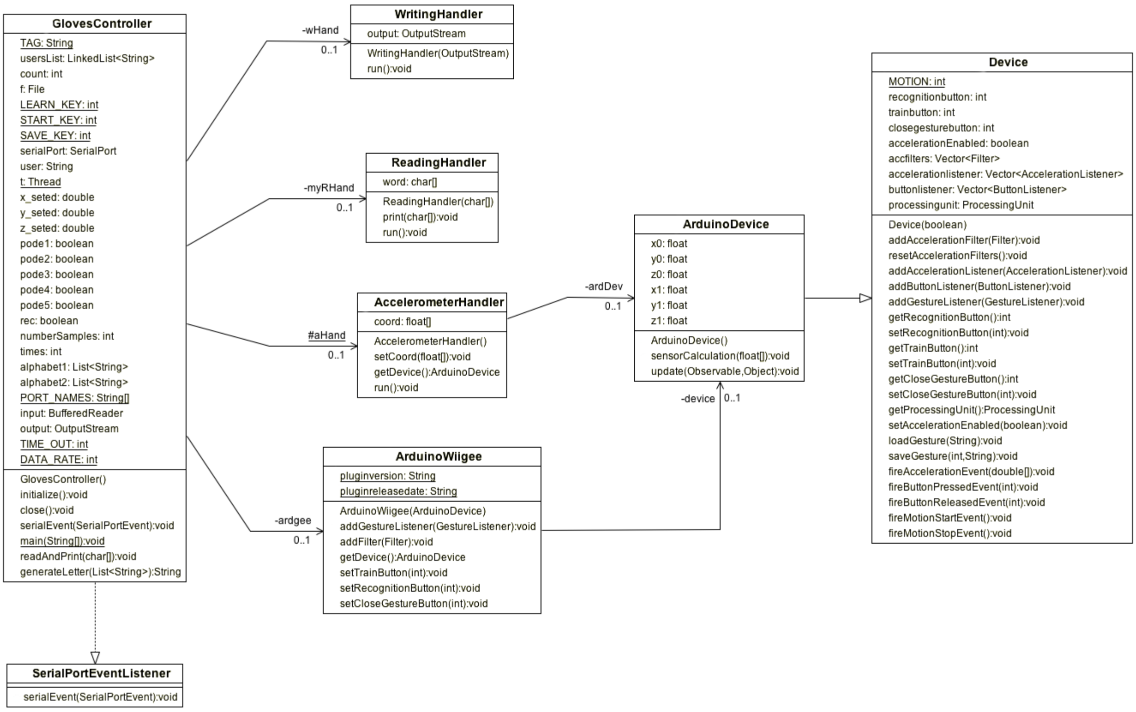


Figure 3.3: Class Diagram for the software part.

3.3.3.1 Controller

The Gloves Controller class is responsible for the reception of all the communications that the controller software will receive from the gloves. This class works essentially as a message broker between the gloves and the handlers. All the messages have an associated tag, this way the broker knows how and to which one of the handlers forward the message. There is three types of tags, one for each handler. The tag *"axis"* means that the message contains a set of data that belong to the accelerometer, when the broker reads the tag knows that the message have to be routed to the Accelerometer Handler. The tag *"word"* it is related to a set of data that represents a word our letter that the user wrote with the gloves. Upon receiving a message with this tag, the message broker sends it to Writing Handler. This tag is also used when the Reading Handler sends a message to the gloves. The third tag, *"button"* is also used by the Accelerometer Handler as an identifier if the gesture is for training or for recognition. The message handler receives this message and sends it to the respective handler.

3.3.3.2 Manager Handlers

As it is possible to observe in Figure 3.3, there are three main handlers that are responsible to process all the information about receiving text, sending text to the gloves, and process all the received information that is related with acceleration events.

- **Writing Handler:** This class represents a thread that reads from the console all the input and sends it to the gloves, but only if the character is valid, i.e. only send letters and spaces. This class sends the message directly to the gloves, with out passing through the Gloves Controller class.

- **Reading Handler:** This class waits for a message that comes from the gloves controller. As explained the gloves controller receive a message with the tag *”word”* and re-routes it for the Reading Handler, that prints what the user have wrote with the gloves. If the character is not identified it prints a *”?”*.

- **Accelerometer Handler:** This class is responsible to notify the observers when there is a change in the coordinates received by the accelerometer on the gloves. Basically when there are changes in the values returned from the accelerometer it creates an array containing the new set of coordinates, and notify the observers that the set was changed. The observer of this class is the Arduino Device class. This class emulates the accelerometer of the system into the system of gesture recognition.

3.3.3.3 Gesture Recognition System

For the gesture recognition system, initially we thought of the development of a basic recognizer only to detect basic movements. Then we came across with a system that uses machine learning to recognize several gestures. This system is called WiiGee [25]. This platform is an open-source gesture recognition library. It is implemented in Java, becoming a platform independent system. It uses a hidden Markov model for training and recognizing user-chosen gestures. As described in WiiGee [25], the system follows a classic recognition pipeline (Figure 3.4).

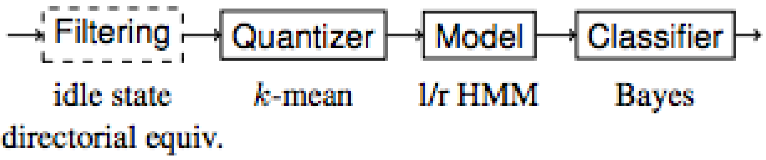


Figure 3.4: Components of wiigee recognition system. The quantizer applies a common k-mean algorithm to the incoming vector data, for the model a left-to-right hidden Markov model is used and the classifier is chosen to be a bayesian. Image retrived from Schlömer et al. [25]

The Filter, removes vectors which are below a given threshold of approx. 1.2g, being the acceleration of gravity, thus eliminating suspected duplicates. The next component is a Quantizer, clustering the incoming vector data in order to generate a discrete code identifying each gesture. Here, a standard k-mean algorithm is utilized, k being the number of clusters or letters. From the theory of speech recognition the authors picked a discrete, left-to-right hidden Markov model, represented on the third component, the Model. In the last component the gesture is mapped to a probabilistic model. This probabilistic model is then classified in a traditional Bayes-classifier, which identifies the most probable gesture during a recognition task.

This system allows us to define our own set of gestures instead of only recognizing a predefined set of gestures. Once we use our own set, the system needs to be divided into two modes, training and recognition. In the first mode, the training mode, it is like a recording process triggered by a specific *TrainButton*. This *TrainButton* must be held down during recording. Releasing it marks the end of the recording process. Repeating this whole procedure further, trains the system making it more likely that a gesture is correctly identified during the later phase of recognition. Once the predefined number of training sessions is reached, it triggers a *CloseGesture* function which concludes the training phase. After this process, the user is now able to perform the newly recorded gestures. For that, the user presses the *RecognitionButton* and holds down during the gesture performance. After the releasing of the button, WiiGee tries to identify the gesture and fires a *GestureEvent* containing information about the detected gesture along with the calculated probability.

In our system, this platform was adapted since it only worked with Wiimote and Android devices. We developed the object Arduino Device that emulates the Wiimote, but uses the accelerometer information given by the gloves. This proved to be a reliable and fast platform to work with, since the recognitions rates, and the speed with which results were returned, was quite fast not making the user wait for them.

3.4 Android Integration

For this project, although all the user tests were performed with the gloves connected to the presented software, that was running on a PC, it was also developed a small Android application that allows some interaction between the mobile device and the gloves. This application was developed in the form of a game. In this game, two users participate, one with the Android device and the second with the gloves. The game develops through an exchange of words through the devices. For example, the user with the mobile phone writes a word, then it the button send, once the word is sent to the gloves, it translates each letter of the received word to braille chords. Then the user feels those chords through the vibration motors. After that, the user with the gloves must write with the gloves the word that he felt, in Braille. When the Android device receives the word it compares with the initial word and if it is the same word, it emits a victory sound, otherwise it emits an error sound.

This application was developed to test the communication between the two devices. It was proved that it works and with more time it is possible to create more interactions not

Figure 3.5: Photo of a user using the presented system.

only for recreational applications but also for accessibility applications, for example, it is possible to create an input method.

An input method editor (IME) is a user control that enables users to enter text. Android provides an extensible input method framework that allows applications to provide users alternative input methods, such as on-screen keyboards, even speech input or physical external keyboards as the gloves. After installing the desired IMEs, a user can select which one to use from the system settings, and use it across the entire system. To add an IME to the Android system, it is possible to create an Android application containing a class that extends *InputMethodService*. In addition, it is usually to create a ”settings” activity that passes options to the IME service. The programmer can also define a user settings interface that is displayed as part of the system settings.

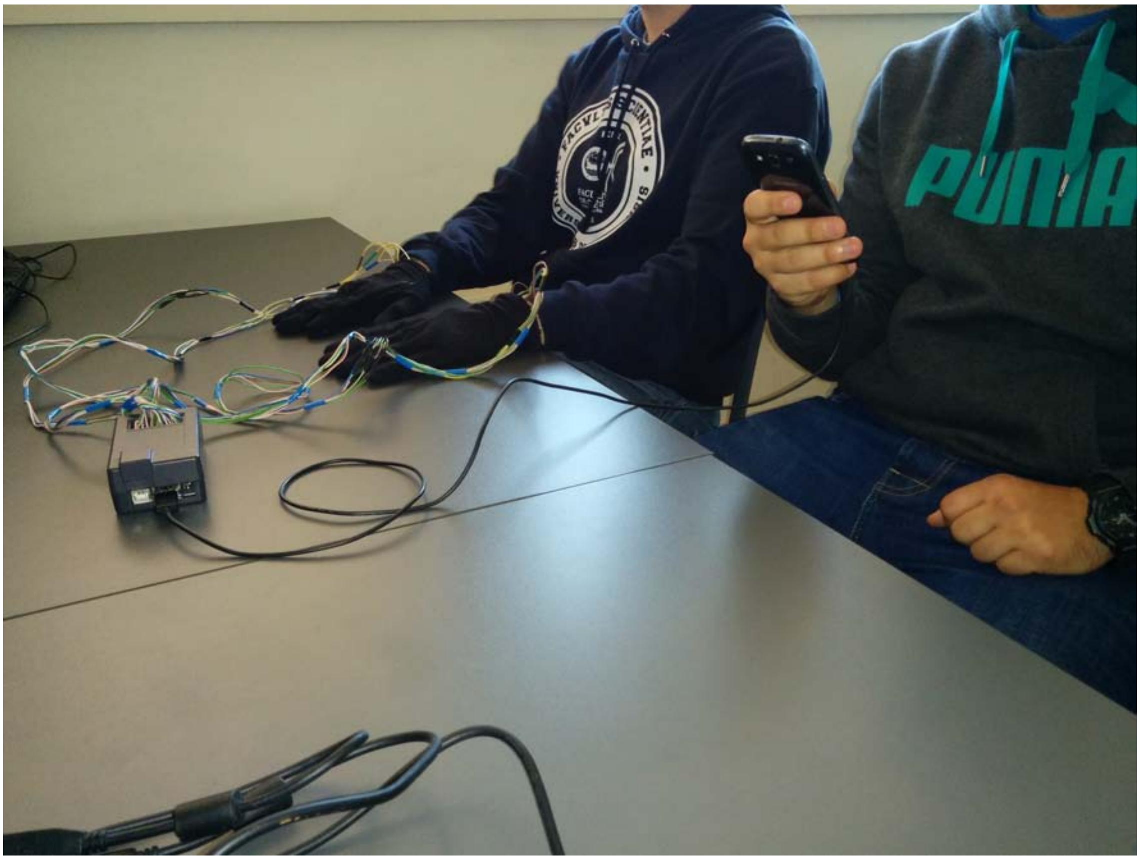


Figure 3.6: Photo of two users interacting through the developed android application.

Chapter 4

Evaluating Wearable Braille I/O

In this section we present a study to assess the writing and reading features with the previously presented prototype. The evaluation was based in Braille alphabet.

This study was performed to evaluate how users react and perform using a wearable device. First we focus on the usability, so that we can understand, in a more clearly and evenly way, what concerns blind people have using a pair of gloves. We aim to know scenarios of usage. Users that perform the performance test suggested those scenarios. During the tests we encouraged them to think aloud, with that data it is possible to measure the receptiveness. Secondly, the performance, how fast and accurately they can write and read.

In this study, the users task is divided in three phases. The first phase consists in feeling stimulus through vibrating motors. These stimuli are based in Braille chords. In the second phase the user has to write all the letters of the alphabet in Braille using the buttons in the gloves.

4.1 Research Goals

This test has the objective to assess the writing and reading braille through a wearable device. These goals are:

- Perceive the acceptance of wearable use by blind users.
- Assess writing and reading features with the prototype.
- Perceive the usefulness through the point of view of users.

4.2 Methods

For this phase, we collect different types of data. As said before this study was divided in three parts. In the first part, we requested the user to try to identify and replicate all letter in Braille, randomly. With this data we can understand if it's possible to read through vibration motors as it was described in Nicolau et al. [15] but this time with a glove. In the second phase the user was asked to write a letter randomly ordered; with this we can observe if it's possible to write Braille through six buttons installed in the fingertips of the glove. In the last part of this test we asked the users if they could write three phrases, with this it's is possible to collect data not only to know if they could but also to know how fast and with how many errors.

4.2.1 Setup

To perform these tests, we used an Arduino Mega ADK, which was connected to the gloves. In this procedure, the Arduino was connected to a PC, which was set to run a program with the test. In this way the whole testing process was automatic. While the program was running and sending letters to the gloves, it generates an XML file containing logs of what was asked by the program and the users answers.

For the post experience, users answered a demographic questionnaire through Google Docs web form. This form started with standard demographic questions and then proceeded to 3 questions related to users concern with privacy, and what is the opinion that they have about using wearable devices. All the answers were collected and saved to a spreadsheet automatically. An image of the setup can be seen in Figure 3.5.

4.2.2 Participants

We recruited 9 volunteers, from ”Fundação Raquel e Martin Sain”. All of them were trainees in that center. From the nine volunteers, six were male and three female. Their ages ranged from 35 to 63 years old, with an average of 48 years old (± 10,7). All subjects were totally blind and six of them had congenital blindness. All of them had knowledge of Braille, only one of them said he only uses Braille monthly; as for the rest, four of them use Braille every day and other four weekly.

4.2.3 Procedure

This test started with a simple explanation of who we are, and what is the apparatus that we will be testing and how it works. After that, we described the procedure, and all the phases of the test that they would go through.

There are three test phases during this test, the vibration test, the writing letters test, and the writing phrases. Then we proceed with a 5 minutes training where the subject trains writing and reading with the gloves. Next, we started the first phase of the test. In this phase, we aimed to test the user capability perceiving vibrations when a Braille chord is sent to the gloves. For that, all the 26 letters of the alphabet are picked randomly and sent to the gloves where the motors vibrate for a period of one second. Then, the user has to try to identify the chord that he felt and replicate it with the glove. Again, the program records in the XML file the chord that was asked and the chord that the user wrote. It is important to notice that this test just assesses what the users felt and were able to reproduce. In the second stage the person who is guiding the test asked a random letter generated by the program and then the subject had to write the asked letter. In the third and last phase the person who is conducting the tests asked the user to write three phrases, that the program selects randomly from a base of six, then the user writes it using the buttons installed on the gloves. Both phrases, the asked and the written were recorded in the XML file and the time that the user spends writing the phrase.

In the end it was made a quick questionnaire about personal information and their opinions about wearable devices. All of the experimental sessions were conducted in the ”Fundação Raquel e Martin Sain”, with this we minimize the environmental impact in the user performance increasing the validity of the results.

4.2.4 Measures

In Section 4.3.1 and Section 4.3.2, we evaluate the performance, using the overall accuracy and error rate. The error rate by letter was analyzed with a confusion matrix, where the accuracy levels are presented for each letter.

For the writing phrases test (section 4.3.3) we adopt other metrics that suit better that task. A method proposed by Soukoreff and MacKenzie [26] for measuring text entry error rate (MSDER) was used to measure the distance between a presented text string(A) and a transcribed text string(B)(see Eq.4.1). The formula presented represents the smallest proportion of characters considered errors given the two strings.

$$ErrorRate = \frac{MSD(A,B)}{max(|A|,|B|)} \times 100\% \tag{4.1}$$

Another metric used in section (4.3.3) was the words per minute (WPM) to assess speed. The WPM was calculated with Eq. 4.2, were ”str” is the transcribed text, 60 is used to convert variable ”time” from seconds to minutes and 5 is the average characters per word. This allows us to evaluate if the method is fast or slow.

$$WPM = \frac{(str-1) \times (\frac{60}{time})}{5} \tag{4.2}$$

4.3 Results

In the next subsections, the results for the three main tests performed with the nine subjects are presented. As you will see, some results are not that encouraging, but the purpose of this case study is to gather as more information as possible about social acceptance and possible scenarios.

4.3.1 Vibration test

The vibration test, which consists in recognizing random Braille characters through vibration. In this test, participants obtained an average accuracy of 31% (±19,32), as showed in Figure 4.1.

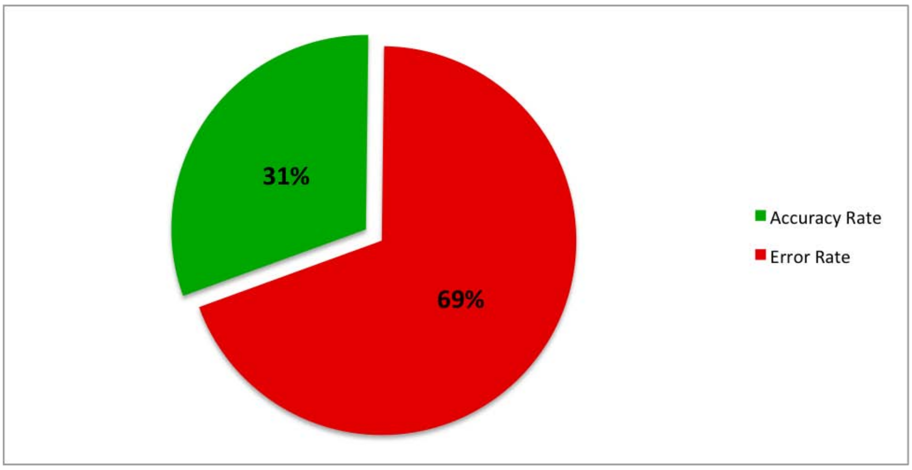


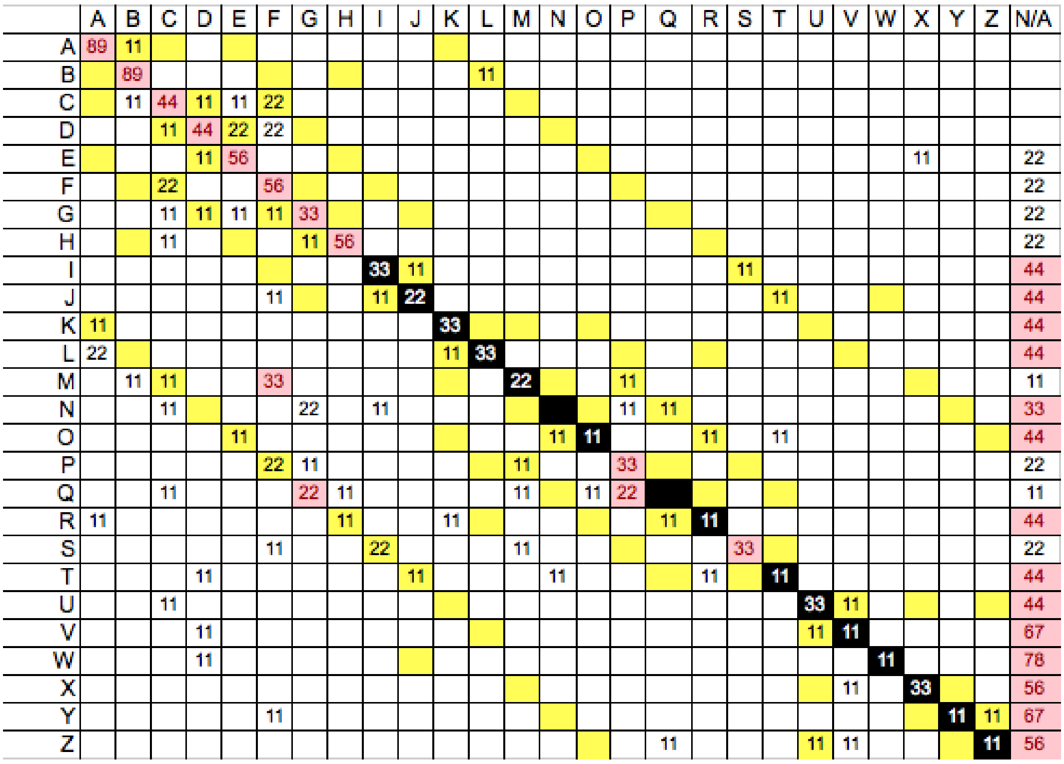
Figure 4.1: Global recognition accuracy and error.

In the confusion matrix presented in Figure 4.2, it is possible to observe the character recognition accuracy, at the same time we can read the link between asked and identified letters. At first sight this data indicates that simpler letters are easier to recognize than the more complex ones. This can be explained by the fact that the subject needs to process more information. Also looking at previous work by Nicolau et al. [15], where the recognition accuracy is higher, it is likely that the gloves themselves are deteriorating the recognition accuracy.

In Figure 4.2, it is possible to see that some letters are harder to recognize then others. For example 'N' and 'Q' obtain a 100% error rate, which means that none of the users was able to correctly identify those letters. But not only these letters are difficult to identify, the characters 'O', 'R', 'T', 'V', 'W', 'Y' and 'Z', obtained an error rate above 80%. In Nicolau et al. [15] they refer that the letters that are harder to recognize are 'N', 'O', 'V', 'Y' and 'Z'. These results are confirming that these characters are problematic.

Big factors that can affect the results are the possible different individual capacities of the subjects studied due to small sample size. Because of that the results can be affected by individual performances (Figure 4.3). For example, two subjects have almost opposite performances. As we can see, User 4 scored 69% accuracy rate, on the other hand User 1 was only 11% accurate. Globally 3 out of 9 subjects, User 2, User 4 and User 9 (46%, 69% and 46% respectively), were able to correctly identify more than 40% of the characters, as the rest scored an accuracy rate below 30%.

Despite these results some users said that they felt improving through time and that, with more training and if they could customize the duration of vibrations they could



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	N/A
A	89	11																									
B		89										11															
C		11	44	11	11	22																					
D			11	44	22	22																					
E				11	56																			11			22
F			22			56																					22
G			11	11	11	11	33																				22
H			11				11	56																			22
I									33	11									11								44
J						11			11	22										11							44
K	11										33																44
L	22										11	33															44
M		11	11			33							22			11											11
N			11				22		11							11	11										33
O					11									11	11			11		11							44
P						22	11						11			33											22
Q			11				22	11					11		11	22											11
R	11							11			11						11	11									44
S						11			22				11						33								22
T				11						11				11				11		11							44
U			11																		33	11					44
V				11																	11	11					67
W				11																			11				78
X																						11		33			56
Y						11																			11	11	67
Z																	11				11	11				11	56

Figure 4.2: Confusion matrix with recognition rate for the vibration test. The main diagonal of the confusion matrix, indicate the results that we should have got. In red are the majority of the responses, and 'N/A' column presents the responses in wish the subjects were unable to identify any letters. Yellow marks the letters that are in a single finger distance.

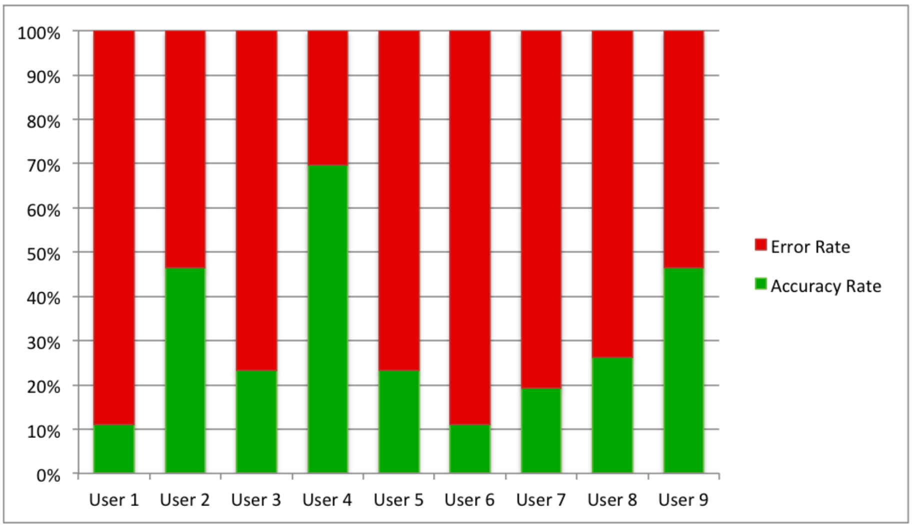


Figure 4.3: Character recognition accuracy and error rate by subjects from vibration test.

achieve considerable performance improvements.

4.3.2 Writing letters test

In this test, participants obtained an average accuracy of 74% (±26), as showed in Figure 4.4. The accuracy rate is much higher then the previously presented test.

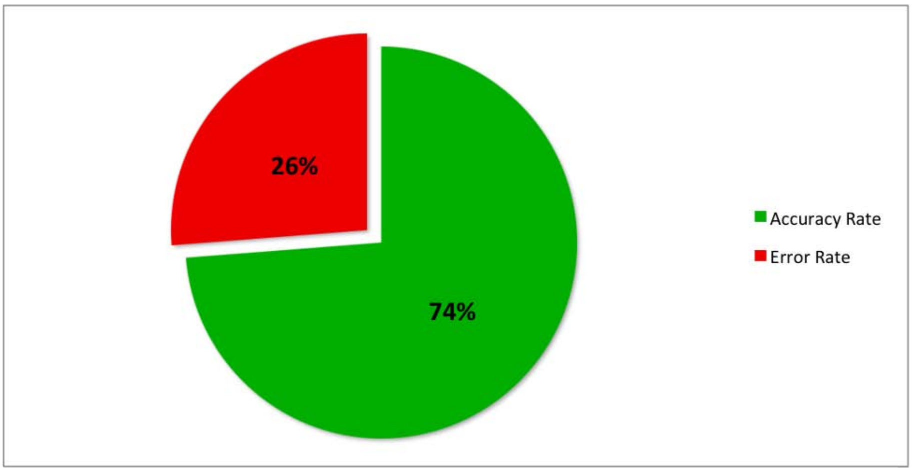


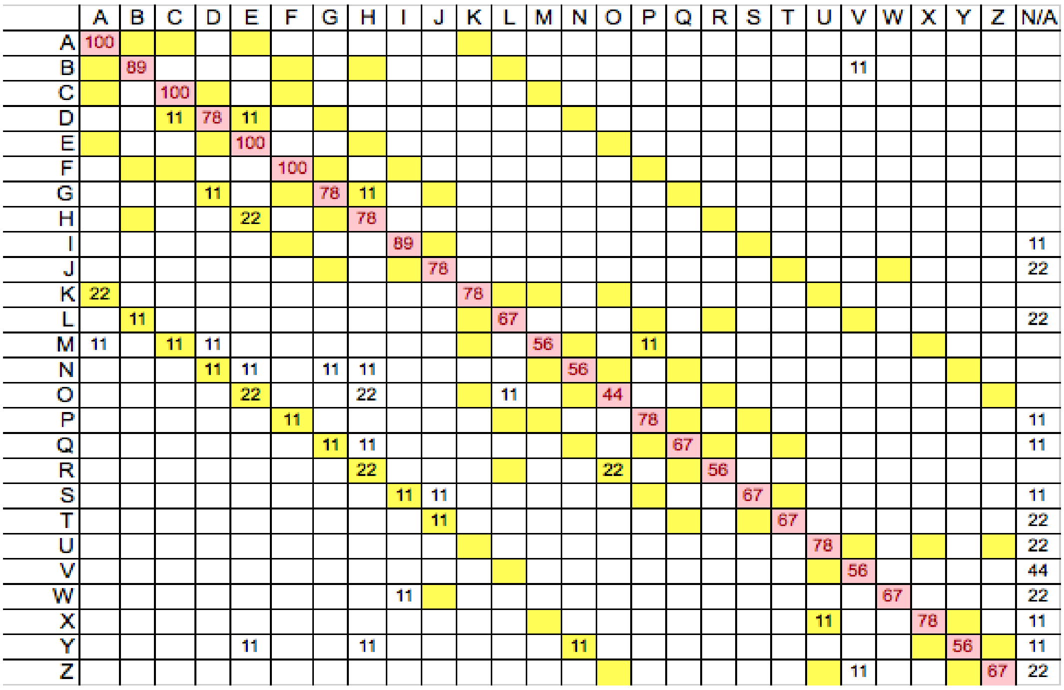
Figure 4.4: Global writing accuracy and error.

In the confusion matrix of this test (Figure 4.5), we can observe that the majority of the results fit in the main diagonal, but it is possible to observe that some letters are more difficult to write than others: this can be related to one finger issues, since a large set of the errors are in yellow cells. For example the diagonal from 'HA' to 'TJ', gathers the larger part of the identifiable errors. We cannot say that most of the errors are due to this problem, since we still have some results in the 'N/A' column, but probably the issue could be the same, once, some of the error due to one finger issues results in a non-letter from the Braille alphabet, which we discarded and tagged as N/A.

In a deeper look through results it is possible to observe that the characters with the higher error rate are 'O', with 56%, 'M', 'N', 'R', 'V' and 'Y', each with 44%. All the other characters have an error rate below 40%, and some even got 0% as the case of 'A', 'C', 'E' and 'F'.

Once again in this test the results were highly influenced by individual performances. As it is possible to verify in Figure 4.6, once again, some users had divergent results. Globally this test generated good results since 5 out of 9 subjects scored an accuracy rate higher than 80%.

These results encourage investigating this input method since almost all users liked the way it works and felt comfortable during the tests. The users showed to be very receptive regarding the use of this type of device for text input not only mobile phones but also on personal computers. Although, some bad results can be related to some type of malfunction in the buttons since they are for prototyping, they do not have the reliability of an end product.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	N/A
A	100																										
B		89																				11					
C			100																								
D			11	78	11																						
E					100																						
F						100																					
G				11			78	11																			
H					22			78																			
I									89																		11
J										78																	22
K	22										78																
L		11										67															22
M	11		11	11									56			11											
N				11	11		11	11						56													
O					22			22				11			44												
P						11										78											11
Q							11	11									67										11
R								22							22			56									
S									11	11									67								11
T										11										67							22
U																					78						22
V																						56					44
W									11														67				22
X																					11			78			11
Y					11			11						11											56		11
Z																						11				67	22

Figure 4.5: Confusion matrix with recognition rate for the writing letters test. The main diagonal of the confusion matrix, highlighted in red, indicate the majority of the responses, and 'N/A' column presents the responses in wish the subjects were unable to identify any letters. Yellow marks the letters that are in a single finger distance.

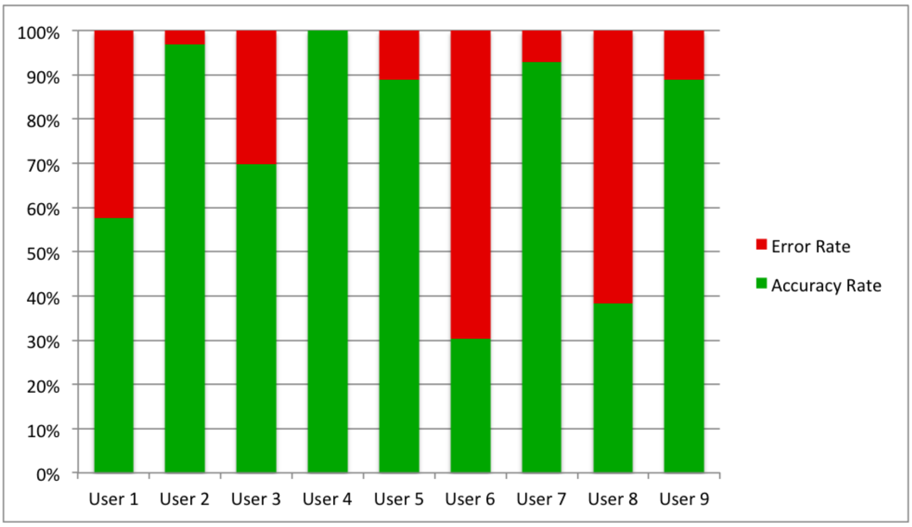


Figure 4.6: Character writing accuracy and error rate by subjects of writing letters test.

4.3.3 Writing phrases test

This test had a similar behavior as the previous test (see Section 4.3.2). In this test, we obtained an MSDER (see Eq. 4.1) of 0,40 (SE = 0,086, 95% CI) on average. This states that the training during the previous test was not enough to develop a good writing ability when the number of characters increases. Three out of 9 users get more then 50% of error rate.

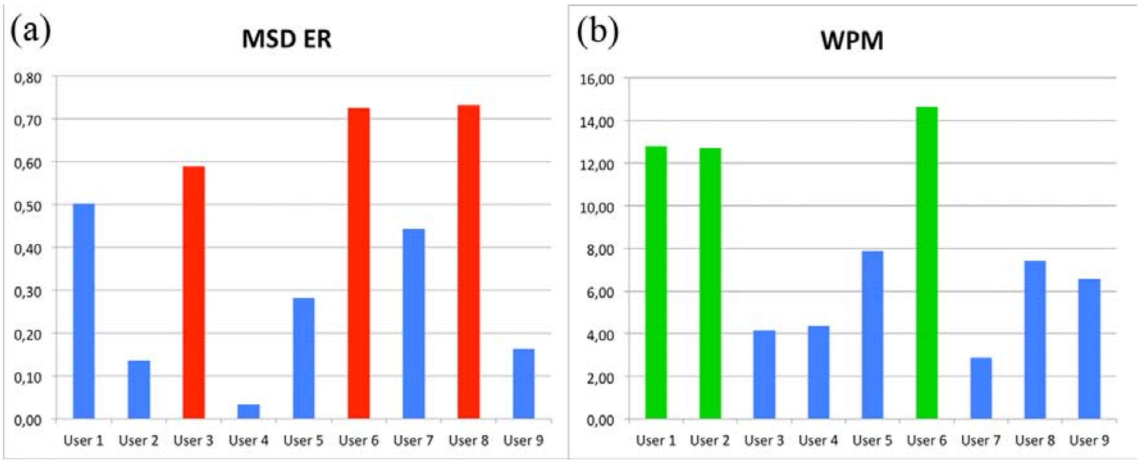


Figure 4.7: Error rate by user and writing speed. (a) Minimum string distance error rate. (b) Writing speed in words per minute. (a) Representation of the error rate per participant, using MSD ER explained in sub-section 4.2.4. Red bars indicate the biggest error rate (threshold ≥ 0,50 error rate) and the blue bars are the users with lower error rates. (b) Green bars represent the user with the fastest writing speed (threshold ≥ 10 WPM) an the blue bars are the slower users.

Regarding writing speed some users showed good writing pace, with three users getting more than 10 WPM. Overall, we manage to obtain and average of 8,16 WPM (SE = 1,42, 95 % CI). With these results we can say that there was not any development over time, which means that users, do not benefit from learning, either through previous test or during the present test.

4.4 Scenarios and Receptiveness

In this section we will describe some scenarios proposed by participants. Later in this section, the receptiveness will be also discussed. These information were gathered from the users during the study.

4.4.1 Scenarios

Some users suggested the utilization of this device in some situations related to the daily life. Most of them related to usage while on the move, such as in public transportation. For example User 2 said that would be nice if people could use this device in buses or in the subway, adding that it would increase their privacy. User 9 has the same opinion as User 2, and stated that it could be more practical when compared with other text input methods. User 5, for example, said that it would be interesting to write a message while he is waiting for the bus.

Another possible scenario proposed is the integration with the iPhone, User 1 is the only participant with an iPhone, and he said that in combination with VoiceOver for reading text it could be very practical using the proposed device while walking.

User 2 and User 4 stated that it would very beneficial if this device could be used in a context of Braille learning. User 2 said that it could be beneficial if two pairs of gloves could be connected with each other: the person that is learning could receives a chord sent by the teacher, and the teacher receive the chord written by the student. User 4 mentioned that receiving the Braille chord directly could help to memorize it faster and easily.

Taking personal notes was another scenario that some users mentioned. They said that personal notes were important to them and that, if allied with software that synchronizes their mobile phones and personal computer, that it would be very useful. User 3 referred that ”taking notes with these gloves would be much easier since it is small and lighter than the Perkins Brailler.

4.4.2 Receptiveness

Regarding the acceptance of users, we had acceptance; only one of the nine participants did not like the presented prototype. User 8 said that he could not distinguish any letter during the vibration test and that he saw no feasibility in the system. This user’s opinions were possibly influenced by the low recognition accuracy.

The other users have accepted well the system and said that if we could improve our device the use cases could be quite beneficial to improve their quality of life. Some users stated that the feedback provided by the actuators was a good feature that helps them to understand what button they have pressed, which helps them to detect possible errors. Two of the users even gave us feedback of how we could improve some features of the device. For example, User 2 said that he thinks that investing in a more sensitive input method could be wrong direction, once a user could touch unintentionally with a finger, increasing the number of error. Another user said that ”Using a monaural headset, with Bluetooth, the issue of privacy is not very relevant and can eliminate the vibration of the readings, which is quite difficult.”.

We realize that some users complained that it was too hard to press buttons, which is not very comfortable. User 6 stated that because of that, sometimes when she wants to press with the index finger she ends up clicking with the middle finger leading to an error.

The idea of being able to connect to mobile phone was well accepted. User 7 said that it ”would be more practical to write messages than with the phone’s keypad.”. User 4 stated that ”this device connected to the phone would be a great advantage since I am more familiar with Braille.” In turn, User 6 said that ”the ability to connect to the phone would greatly facilitate his interaction with smartphones.”. Connected to this idea, some users declared that with the gloves connected to a mobile device, privacy is maintained. User 3 refered that since there are not many people who know Braille, nobody couls see what they are writing. User 4 said that ”a person being in the street is more exposed to intrusive eyes, and with this device it would be possible to write a message in disguise." and goes even further adding, "As I can write with it in my pocket, it is safer because it can prevent some robberies."

We asked some of the users to try, informally, to write on their legs, and they claim to be very hard and the pressure exerted can, some times, be very uncomfortable. Novel designs are required to enable such inconspicuous scenarios.

This feedback proved to be very positive increasing our knowledge on the subject and helpful for further investigations.

4.5 Discussion

Regarding the first test (see Section 4.3.1), the obtained results were not what we expected, but with the performed tests we can understand more clearly what happened and what caused such high number of errors. We can explain this elevated number of errors comparing with the results reported in Nicolau et al. [15]. First we only use a vibration time of 1000 ms, in this particular case they get a 64% accuracy rate. This means that we have almost half the precision that they got, and secondly, in our study, after they perceived the vibration on their fingers, they have to reproduce the Braille chord with the buttons installed in the gloves. This can add more error rate due to malfunction of the buttons or the lack of experience writing with this type of buttons. As you can see back in Section 4.3.2, the error rate only on the writing part is 26%. Adding this, the error rate obtained, about 69%, isn't totally unexpected. The rest of the error rate can be attributed to the design of the glove. For that, two explanations are possible, one can be related to lack of vibration damping, as for example, the vibration actuators are sewed to the glove, which will cause the vibration to spread throughout the hand, and nearest to the fingers. The second could be related to some malfunction in the buttons or inexperience using this type of input.

In Section 4.3.2, possible several causes for the errors can appear. For example the lack of training that they have could lead to a higher number of errors; they only had 5 minutes to train before they started the test. Another reasonable cause for inaccuracy can be related to some kind of malfunction in the buttons or technical problems related to the wires. Despite that, one of the main reasons for the errors is related to one-finger issues; documented, we have about 26%, but based on user's feedback we know that most undocumented errors are of this type. Undocumented errors are chords that we could not identify, due to the fact that big part of these mistakes do not match any known Braille chord. For example User 6 said that, "one problem that may exist is that when you press with your index finger can end up clicking with the middle finger". This confirms what was previously stated.

In these first two tests, we tested if there were differences between individual capacities. These tests revealed that in fact individual abilities have a significant impact in the outcome of the obtained results, and also gives space for training and improvement.

In the last test performed, the high rate of errors can be related to the fact that users want to write too fast for the experience they have with the device leading to unintended errors.

In summary, regarding the reading feature, a lot of work must be done related to vibration damping, although it can be minimized by the increase of vibration time. Regarding the writing feature, results are promising and with more experience it could be a good method to consider when compared with the alternatives.

Chapter 5

Preferences and Performance of Blind Users in a Gesture-based Interface

This chapter describes a study with the main objective of better understanding how blind people physically interact with a mid-air gesture-based interface. While previous studies focus on touch screens [12] and for blind people mid-air gestures have been explored only for sighted people, there is a lack of knowledge of how blind people could use this technology with smartphones [24]. This study explores possible design guidelines to create accessible mid-air gesture controllers; for that we also compare how blind and sighted people interact with such devices, aiming at an universally-accessible method.

5.1 Motivation

Despite the hype around new wearable devices, there is limited knowledge about their accessibility, or about how these devices can make personal computers and smartphones more accessible. For that several challenges must be overcome.

First, despite the existence of technology for that, little is known about three-dimensional gestures. In Wobbrock et al. [29] and Kane et al. [12] the absence of understanding about two-dimensional gestures is addressed and in Ruiz et al. [24], they do not include blind people in their study. This paper presents a study about motion gestures, but in a direct way, by manipulating the device him self, what could mean that if we remotely manipulate the device the result could be much different. Also this study does not include blind users on it.

Second, the rapid spread of wearable devices, demands that when designers develop this type of devices consider if those equipments will be as easy for a blind user as it will for a sighted user, and if it will work efficiently for those two types of users. In this specific case, detection of motion gestures, they will use the same device but for the same action they may prefer to use a different gesture. Since a blind users lack three-dimensional knowledge, it is expected that they will preform differently.

These questions raise more doubts about how well will blind users perform in a three-dimensional space. In this work we try to identify what gestures are more natural, and easy for sighted and blind people. To answer these questions we conducted two studies, the first one is a gesture elicitation study, and the second is a performance test.

5.2 Study 1: Gesture Elicitation

This study consists in eliciting gestures for common tasks, based on previous studies [28, 29, 12, 24].

5.2.1 Methodology

This test was performed to better understand how blind people prefer to interact with their smartphones through motion gestures, captured by an accelerometer. To do that we ask blind and sighted users to suggest gestures that could be used to perform some tasks on smartphones. Asking both populations enables us to be aware of the differences in preference between sighted and blind people, and thus designing future interfaces accordingly.

5.2.1.1 Participants

For this study, 10 blind (with light perception at most) users were recruited (6 female, 4 male, with an average age of 48,1 and SD = 10,7) and 10 sighted users (4 female, 6 male, with an average age of 24,4 and SD = 0,8).. These blind users were recruited from ”Fundação Raquel e Martin Sain”. All of them were students in the center. The sighted population was recruited in the local university. In both populations, 11 people use smartphones (9 sighted and 2 blind) and 9 normal phones with physical keys (1 sighted and 8 blind).

5.2.1.2 Setup

For this test, we had a setup composed by a list that was given to users with tasks from which we want users to recommend gestures. In addition, we installed a video camera that captured the gestures that users recommended, as well as users comments. Think-aloud was encouraged.

5.2.1.3 Procedure

The protocol was developed based on several previous elicitation studies [29, 12, 24]. The study participants were sitting at a desk in front of a paper describing the task set. These tasks were organized in two categories, Action and Navigation, and in sub-categories, system tasks and application tasks. The list, included 18 tasks. The objective of the experiment was explained to users and once they were ready to begin the camera was set in record mode.

In this experiment tasks were derived from Ruiz et al. [24]. The tasks used in our study were: answer call, hang-up call, place call, ignore call, activate voice search, go to home screen, next application, previous application, next photo/song, previous photo/song, next contact, previous contact, rotate left, rotate right, rotate up, rotate down, move object closer and move object away.

The users do not have any object or device in their hands. This avoids that users suggest a gesture that is oriented for a specific object or device. At any point of this study no feedback was given to the users. This way we avoid any influence on the suggestions of users. Although, the user can change any gesture at any point of the experiment. After this process, the experimenter ask the participant to respond a quick questionnaire about personal information and asked to grade their set of gestures on their intuitivity to other users, in a scale from one to five.

5.2.1.4 Measures

In this study, we calculated the agreement level for each task. For this calculation, we adopted a method that was presented in Wobbrock et al. [28]. We used equation Eq. 5.1, where ”A” it is the degree of consensus, ”P_t” is the set of proposed gestures from ”t”, an ”P_i” is the subset of similar gestures from the proposed set for task ”t”.

$$A = \sum_{P_i \subseteq P_t} \left(\left| \frac{P_i}{P_t} \right| \right)^2 \times 100\% \tag{5.1}$$

5.2.2 Results

For this study, 20 participants were recruited and each of them suggested 1 gesture for each of the 18 tasks. In total, we collected 360 gestures (20 x 18 = 360). In this section, we will analyze the differences between sighted participants suggested set and blind participants set. This information will inform the design of future motion-like gesture interfaces.

5.2.2.1 Gesture Ratings

In the end of each trial the subjects were asked to evaluate the set of gestures that they suggested, as to its intuitivity to other users. The participants rated the set of gestures using a scale from 1 = unintuitive to 5 = very intuitive. Overall, the average score was 3.7 (SD = 0,92). In particular, the blind participants graded their set with an average score of 3.8 (SD = 1,14), and sighted participants evaluated the gestures created with an average score of 3,6 (SD = 0,7).

5.2.2.2 Gesture Properties (Taxonomy of Motion Gestures)

For this evaluation, we used a gesture rationale based in a taxonomy presented in Ruiz et al. [24]. The only difference was the removal of the kinematic impulse since that the necessary information was not retrieved during the tests.

The taxonomy presented is divided into two taxonomy dimensions, gesture mapping, and physical characteristics. The first one it is nature based, context and temporal. The nature dimension defines that the symbolic gestures are visual representations, this dimension is divided in metaphor, in which the gesture is a metaphor of another physical object, physical where the gesture acts physically on an object, symbolic that the gesture visually depicts a symbol, and abstract where the gesture mapping is arbitrary.

The context dimension states whether the gesture needs specific context or not, if there is more then one action for the same gesture. The context in which it is performed is required to understand what is the action that the user pretends to do.

The temporal dimension describes if the action on an object occurs during or after the performed gesture. A discrete gesture describes a gesture where the action occurs after the gesture. In a continuous gesture, the action occurs during the gesture.

For the physical characteristic, we defined two dimensions. The “dimension” of a gesture, and complexity. The “dimension” of the gesture describes the number of axis that the gesture involves. Single-axis movements are mainly 2-D gestures like flicks, tri-axis gestures are 3-D gestures, such as translation or rotation, and six-axis gestures include a translation and rotation. Finally, the complexity dimension is sub-categorized in simple and compound. The simple sub-category is a gesture that consists of a single gesture. The sub-category compound describes a gesture that can be decomposed into more than one simple gesture.

Taxonomy of Motion Gestures		
Gesture Mapping		
Nature	Metaphor of physical	Gesture is a metaphor of another physical object
	Physical	Gesture acts physically on object
	Symbolic	Gesture visually depicts a symbol
	Abstract	Gesture mapping is arbitrary
Context	In-context	Gesture requires specific context
	No-context	Gesture does not require specific context
Temporal	Discrete	Action occurs after completion of gesture
	Continuous	Action occurs during gesture
Physical Characteristics		
Dimension	Single-Axis	Motion occurs around a single axis
	Tri-Axis	Motion involves either translational or rotational motion, not both.
	Six-Axis	Motion occurs around both rotational and translational axes

Complexity	Simple	Gesture consist of a single gesture
	Compound	Gesture can be decomposed into simple gestures

Table 5.1: Taxonomy of Motion Gestures. List with the full taxonomy used to classify the suggested gestures.

With the presented taxonomy, the suggested gestures were classified. This classification was obtained from the analysis of their comments. In Figure 5.1, the general classification of the gestures is illustrated. With the help of Figure 5.1 it's possible to conclude that the gestures invented by the participants tend to be physical, in-context, discrete and simple, and use only a single axis.

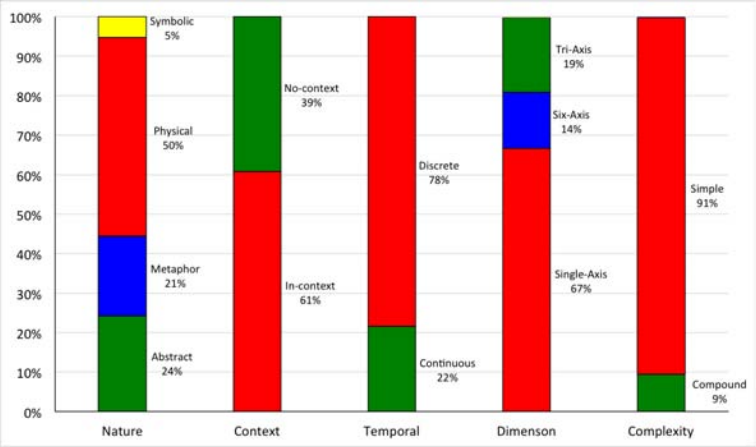


Figure 5.1: Global classification of the gestures taxonomy. Overview of the taxonomy of the suggested gestures by users in percentage(%).

About the nature of the invented gestures, we can see in Figure 5.2 the differences between both populations. Through this graph it is possible to see that blind people suggest more abstract gestures than sighted people and that sighted people invent slightly more physical gestures than blind people. In the other categories, the differences are almost non-existing between both populations. The utilization of more abstract gestures by blind users can be explained by the lack of physical references.

Regarding context, in Figure 5.3, blind participants used considerable more in-context gestures than sighted participants. This happens because blind users use the same gesture for more than one task. During the experiments, it was possible to note that blind users use more flicks than sighted users. Using the same simple gesture for several tasks led to an increase of contextual need.

In terms of the temporal dimension (see Figure 5.4) blind users use slightly more discrete gestures than sighted users. Again, this can be explained by the lack of spatial

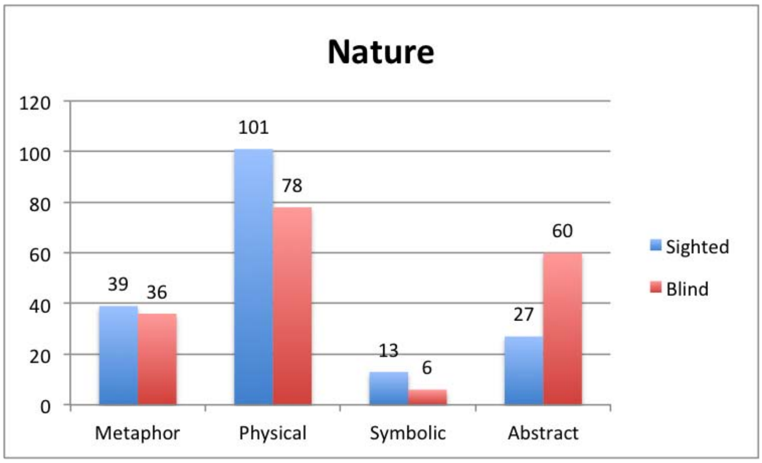


Figure 5.2: Nature of the invented gestures by population. Nature of the invented gestures for each population in absolute numbers.

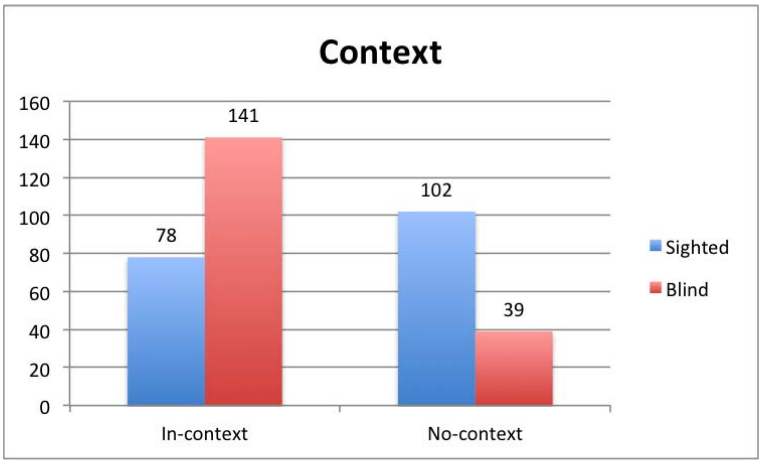


Figure 5.3: Contextualisation of invented gestures by population. Comparison of the contextualisation between blind people and sighted in absolute numbers.

awareness by blind people. Globally, both populations invented more discrete gestures then continuous. Regarding the temporal dimension, we can conclude that in gestures invented users pretend that the action occurs after the end of the gesture.

Related with the dimension of the gesture, the number of axis involved in the gesture, it is possible to observe in Figure 5.5, the blind population uses more gestures that involve a single-axis than the sighted population. In the others categories, tri-axis and six-axis, more sighted users suggested gestures of this type. In this classification in both populations the invented gestures, that involve only a single axis is more than half of the invented gestures.

At last, the complexity dimension of the gestures involved are, in both populations, mostly simple, in other words, the majority of the suggested gestures are gestures that can not be subdivided in more then one gesture. This results can be verified in Figure 5.6.

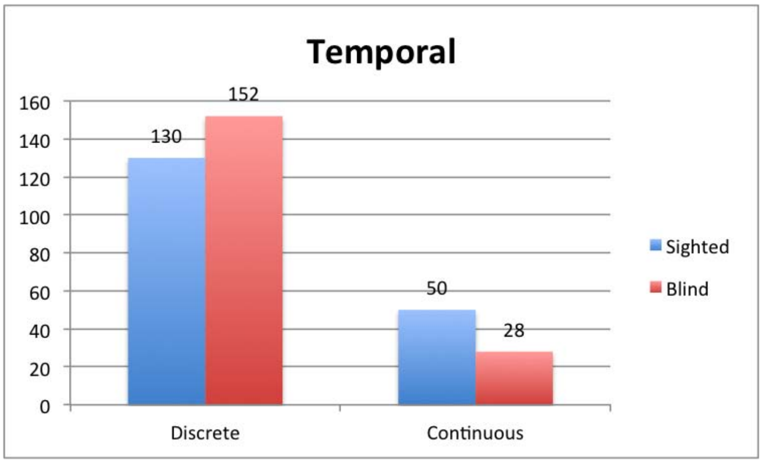


Figure 5.4: Temporal dimension of invented gestures by population. Comparison of the temporal dimension between blind people and sighted in absolute numbers.

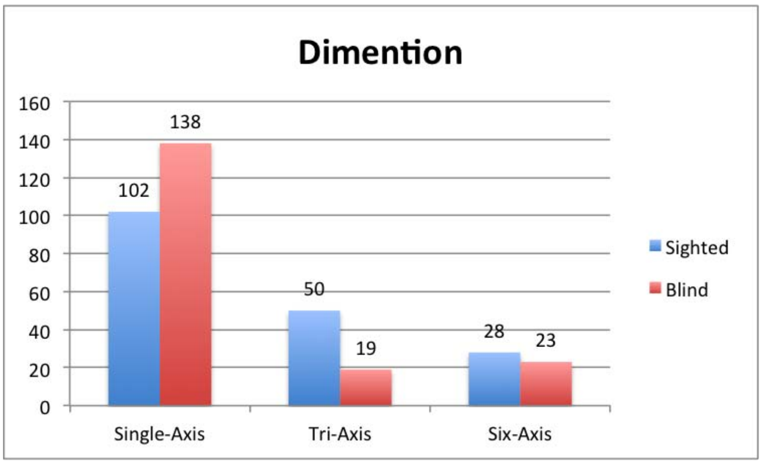


Figure 5.5: Dimensions of the gesture of invented gestures by population. Comparison of the dimensions (number of axis involved in the gesture) of the gesture between blind people and sighted in absolute numbers.

These last two gesture dimensions reveal that both populations, blind and sighted, prefer simple gestures, with only one gesture and with a single movement. This can demonstrate that people associate this type of gestures with faster memorization and effectiveness.

5.2.2.3 Agreement

When developing a user-defined gesture methodology, it is very important that when creating a set of gestures for specific tasks, especially when the target groups of users are so different, such as the sighted population and the blind population, to evaluate the degree of consensus for our participants.

It is possible to observe in Figure 5.7, that the actions place call, go to home screen and ignore call were the less consensual among our participants, and the actions of next,

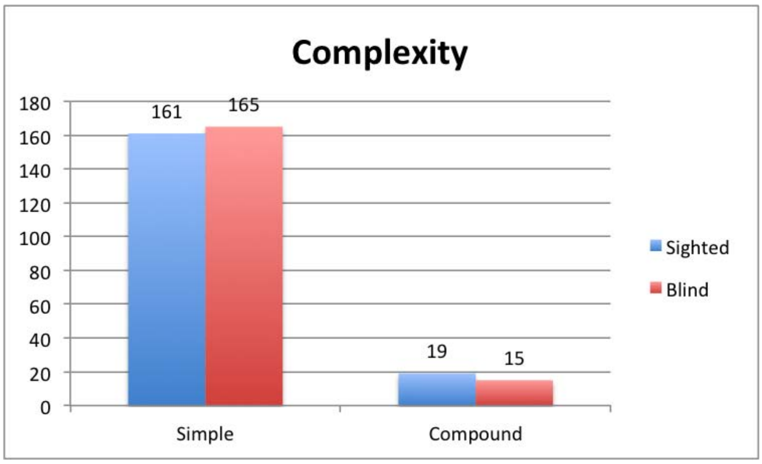


Figure 5.6: Complexity of the gesture of invented gestures by population. Comparison of the complexity of the gesture between blind people and sighted in absolute numbers.

vertical and horizontal, and previous, vertical and horizontal were the most consensual in our study group.

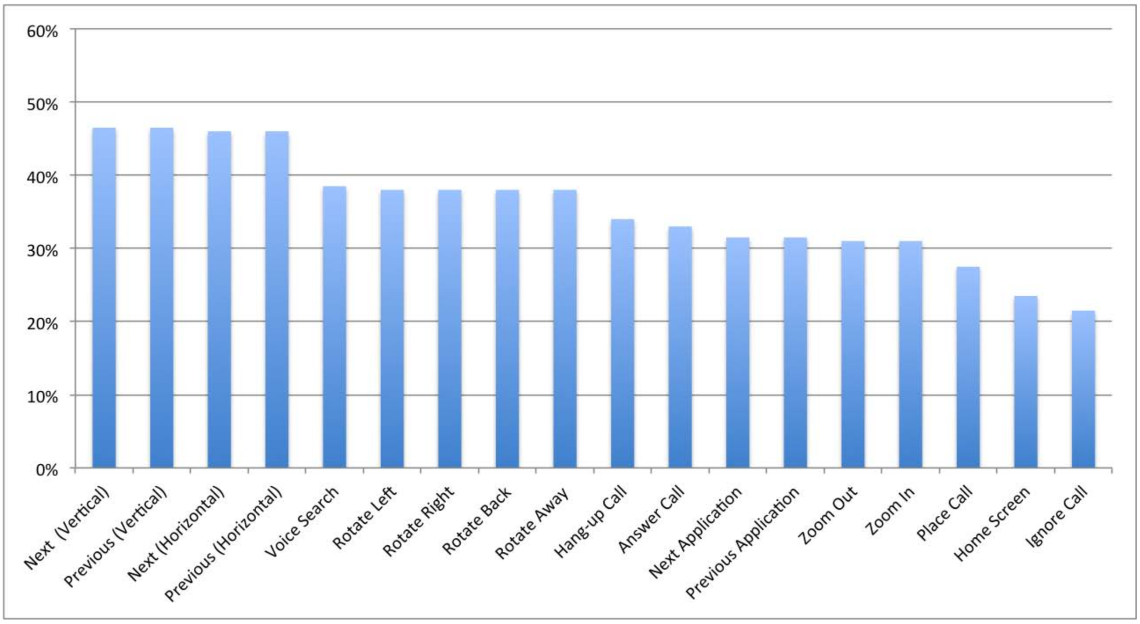


Figure 5.7: Level of agreement for each task. Users agreement for each task in percentage (%). The tasks are ordered in descending order.

Using these results it was possible to create a user-defined gesture set for the proposed tasks. Based on the results that were obtained in this study, we chose to exclude the gestures with less than 30% of agreement. After that, some tasks have the same gesture assigned so these tasks were removed from the final user-defined set of gestures.

The final set of gestures was defined with the suggested gestures for the following tasks: answer call, hang-up call, voice search, next horizontal, previous horizontal, next vertical, previous vertical rotate right, rotate left, zoom in/move object closer, and zoom out/move object away. This user-defined set is shown in Figure 5.8.

5.3 Study 2: Gesture Performance

5.3.1 Methodology

The gesture elicitation experiment gave us some knowledge on how to design such interfaces. With the agreement found, and with the results presented later on, we developed a set of gestures that may serve both populations. To determine if this set of gestures work for both we conducted a second study. In this study, we used four different training sets, the first based on the user's own gestures, user training set; the second based on the sighted users population gestures, sighted training set, the third in the blind population users gestures, blind training set, and the last one, based on both populations gestures, the general training set.

5.3.1.1 Participants & Setup

This test featured the same participants as the previously presented study. In this experiment, participants used an Arduino Mega ADK, which was connected to an Sparkfun ADXL345 Breakout accelerometer. The ADXL345[1] is a small, thin, low power, 3-axis MEMS accelerometer. This accelerometer was then sewed to a Velcro strap. The Arduino board was then connected to a Mac Book Pro, that ran a Java program with an adapted WiiGee library to create the training sequence for each user.

5.3.1.2 Procedure

The protocol for this study contains three phases. The first phase consists in explaining each gesture to the users. In each gesture, we ask the user to execute them so we can verify if they learned properly the gesture. After all gestures are studied, properly we placed the Velcro strap on the user's wrist (the user may choose between left and right).

Then the second phase starts, in this phase users have to perform 11 times each gesture, using the Velcro strap with the accelerometer. Each trial was recorded in two log files, the training sequence of each gesture and the gesture file with the raw values of the accelerometer.

The third phase consists in creating several gesture models, with the different training sets collected during phase two. And then run, the eleventh gesture collected for each task, against the four gesture models created.

The gestures used were for the tasks of: answer call, hang-up call, activate voice search, next photo/song, previous photo/song, next contact, previous contact, rotate left,

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[1] Sparkfun https://www.sparkfun.com/products/9885

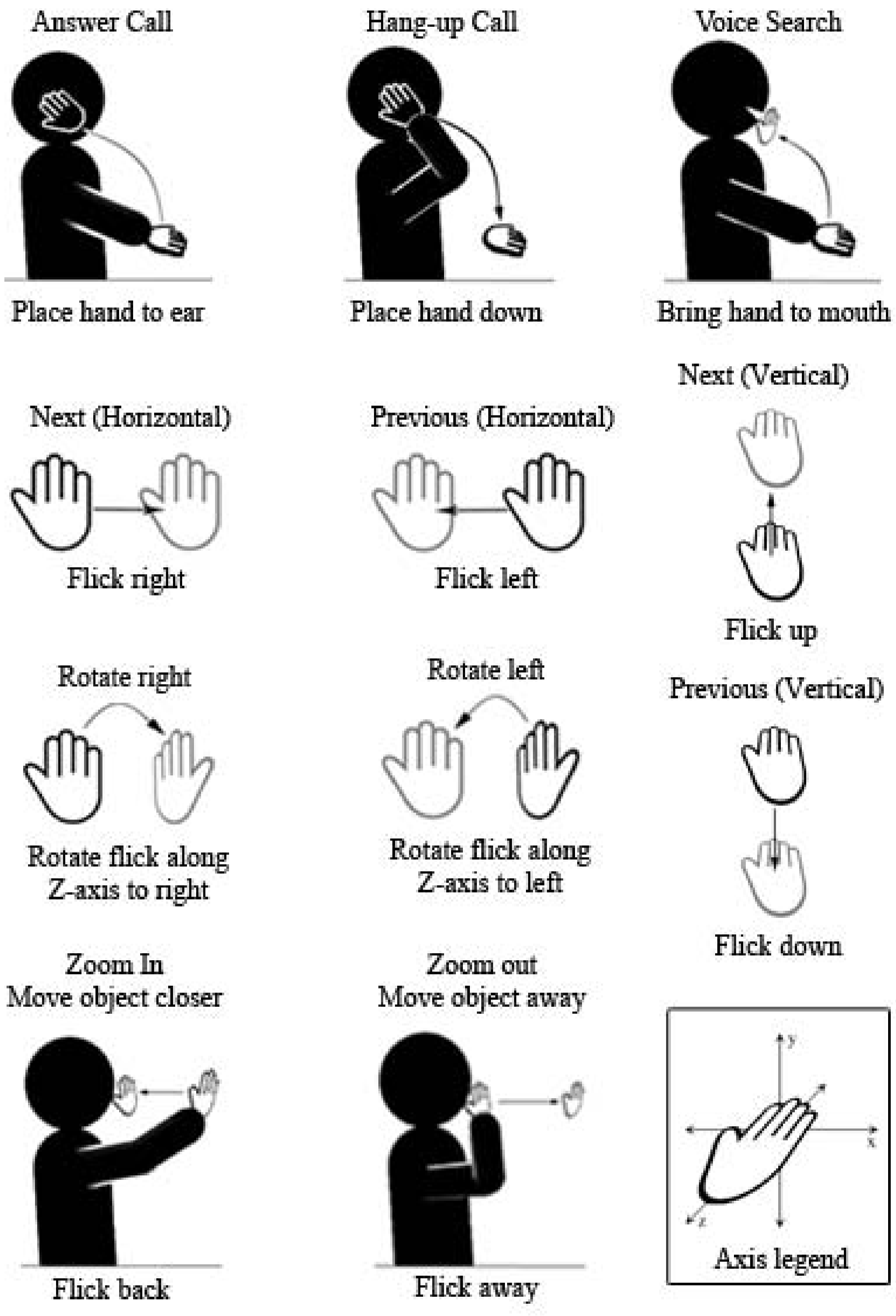

Figure 5.8: The user-defined gesture set. In these images it is possible to see how to preform the user-defined gestures set. The tasks to place a call, go to home screen and ignore call due to the lack of agreement were not included. For better understanding the axis legend shows that in the flick and rotate gestures the hand starts in the plane XZ.

rotate right, zoom in/move object closer, and zoom out/move object away. Users were not allowed to skip any gesture if it was necessary the gesture be trained again.

5.3.1.3 Measures

In this study for the comparison between the different trainings, we used statistical tests to assess if there were significant differences in recognition accuracy. We ran Shapiro-Wilk normality test to assess normality of the data. Recognition accuracy that did not follow a normal distribution; non-parametric alternatives were used, (Friedman and Wilcoxon tests).

5.3.2 Results

For this study, each one of the 20 participants, 10 were blind and 10 sighted. We asked them to perform each of the user-defined set of gestures 11 times. In total, we collected 20 x 11 x 11 = 2420 gestures.

The idea behind this study is that when implementing a system that detects and distinguish different gestures, what type of training maximizes the accuracy rate. The system presented is based on WiiGee. Using a system based on a recognizer arises some questions like: ”what is the best way to train the system?” and in this gesture performance study we address this problem. For that, we will test the accuracy of the different participants in four different types of training. The first type of training was the user training. The second type is the sighted training. The third type the blind training. And for the fourth we used the global training.

5.3.2.1 Recognition Accuracy

Figure 5.9 and Figure 5.10 show the basic results of this study. It is possible to observe that the user training set maximizes the recognition accuracy.

When blind people used the application, statistical tests showed that the differences were significant across the four tests ($\chi^2(3)$ = 20,457, p = 0.000). Pairwise, differences between sighted training set and blind training set were non-significant (Z = -1.913, p = .056, r = 0.43), another result that was non-significant was blind training versus general training set (Z = -0.061, p = 0.951, r = 0.01). However there were significant differences between the user training set versus sighted training set (Z = -2.818, p = 0.005, r = 0.63), versus blind training set (Z = -2.670, p = 0.008, r = 0.60), and versus general training set (Z = -2.814, p = 0.005, r = 0.63). There were also significant differences between the global training and the sighted training (Z = -1.998, p = 0.046, r = 0.45). Taken together, these results suggest that a personalized recognizer have a significant effect on the recognition rate of the gestures in blind users.

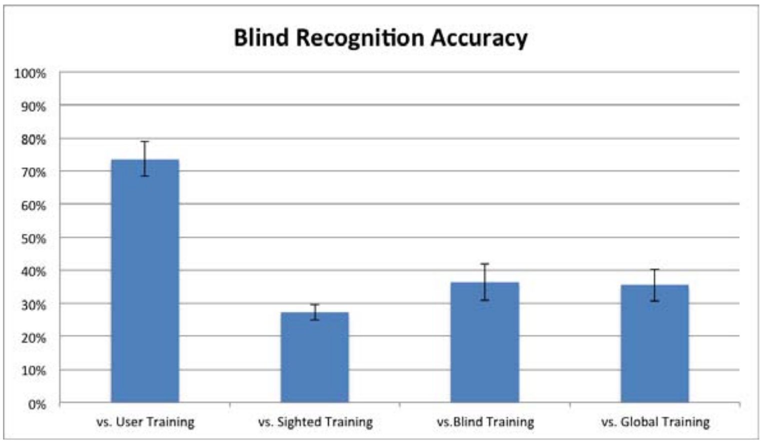

Figure 5.9: Recognition accuracy. The percentage of accuracy of blind population in each of the four tests. Error bars indicate Standard Error.

When sighted people used the gesture recognizer, differences were significant across the different trainings (F(3,36) = 10.88, p = 0.000). The effect size for this test, calculated using eta squared, was 0.48, which is considered a large effect size. A post-hoc test for comparison between groups showed that the mean score for user training (M = 0.6, SD = 0.18) was significantly different than the sighted training (M = 0.32, SD = 0.16), the blind training (M = 0.22, SD = 0.12), and the global training (M = 0.39, SD = 0.15). However, the remaining trainings did not significantly differ from each other. Sighted users obtained similar results as blind users, which mean that a personal training set is the more efficient way to maximize the recognition accuracy in both populations.

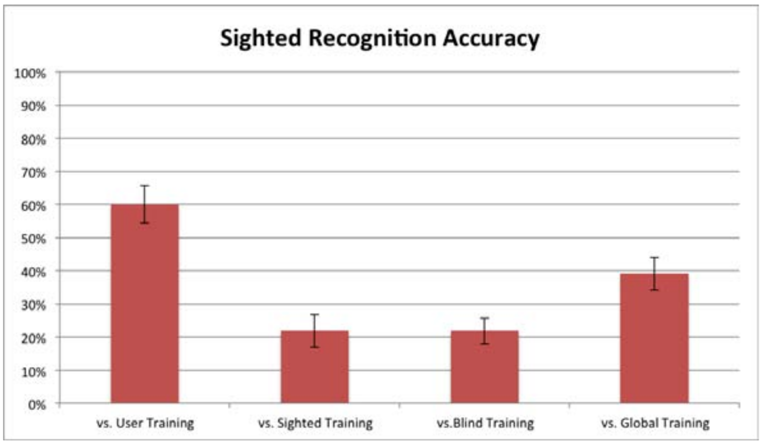

Figure 5.10: Recognition accuracy. Accuracy rates for the preformed tests, for the sighted population. Error bars indicate Standard Error.

5.4 Design Guidelines

These two studies provide a wide range of information for future gesture based interfaces. When designing interfaces for blind people and sighted it is important to take into account several aspects of interaction.

The first one is that the designer must favor simple gestures, in other words, gestures that consist in a single movement. Using these types of gestures allows a better accessibility, since blind users may have reduced spatial awareness.

Metaphorical gestures must be taken into account, as they are easily memorized and easy to understand. This type of gestures must be applied to tasks that exist in and out of the smartphone context, such as, answer and hung-up calls. These gestures got one of the highest agreement rates, so not only blind users prefer this type of gestures but also sighted users.

Physical gestures are strongly encouraged because they were the most suggested gestures of all. This could mean that users tend to manipulate the content of the viewport, as it was a physical object. Not only blind but also sighted participants favor this type of gesture.

One thing that was observed while the study was performed, is that blind people tend to perform the gestures slower than sighted people. With that in mind a time/speed recognition feature will result in higher error rate among the blind users. The size of the gesture must be taken into account, as the gestures performed by blind subjects were, not only slower, but also they have a higher amplitude. So, with this information, the gesture recognizer must have those parameters into account.

The system should be aware of the context where the gesture is performed, because blind users use the same gestures for different tasks. Creating a set with a large number of gestures can lead to more confusion for such users. In this case, having mores gestures to remember may lead to a certain level of frustration, which can lead to forsaking the interface.

The recognizer must be based on training from the user that will use the interface. As the results show, the best recognition accuracy rates were obtained when the recognizer was based on user training. Based on these results it is recommended that, when such interface is designed, a calibration function should be integrated, so that the accuracy becomes maximized.

5.5 Discussion

In this chapter, we presented two studies that try to understand what issues designers have developing gesture-based interfaces that work equally well for blind and sighted people. In the first study, it was observed what preference both populations have regarding a gesture-based interface. This was accomplished by asking both groups to suggest gestures for several day-to-day tasks that they perform with smartphones. In the second study, it was observed in what conditions both groups, blind and sighted users perform the same set of gestures.

Both studies try to answer two questions related to designing gesture-based interfaces. The first, given the choice, would blind users perform different gestures than sighted users? The second, inside each group, blind and sighted users, the recognition rate is better when it is based on their own gestures, based on the group gestures, or based on global gestures?

In response to the first question, it was observed that blind users tend to use simpler gestures, ”Flick's” mostly. This leads to a bigger burden on context aware, since the suggested gestures by blind subjects were very limited when compared to a more diversified set suggested by sighted users. Blind users also demonstrate a slight preference for abstract gestures than sighted people.

In response to the second question, a training set based on the users own gestures proved to be the most efficient, when compared with the other training sets. These results may mean that variations between the users regarding speed and amplitude could be too large to overcome. In this way, we can then conclude that a personalized training set is the most efficient.

As wearable interfaces are increasingly used, to interact with computers and smartphones, it is important that blind people, can use them with similar standards of effectiveness as sighted people. Both studies try to provide new information about how blind people interact with gesture-based interfaces, and how to maximize their efficiency. This work brings directives and more insight about how to build such interfaces that work in the same way for sighted and blind people.

Chapter 6

Conclusion

In the first chapter of this dissertation, we presented the main goal of this project: to design a wearable interface that allows blind people to interact with touch screen devices. In this chapter we will resume the progress made towards this goal. Furthermore, we suggest several future research directions that could provide the next steps along the path to reach the final product.

To achieve this goal, we developed a wearable interface based on a glove; the user can wear it and it will allows him to read, write, and recognize mid-air gestures. For that, two components of the system were developed: the hardware component and the software component. This work was focused in the validation of the design, through usability tests. With the information collected during the project, it was possible to understand what, and how the target users think when interacting with the proposed prototype. It was possible, through our results, to get an idea about how they handle wearable interfaces and their acceptance of such interfaces. Beyond that, performance data regarding ability to perform gestures, and their preference, was retrieved, and compared with sighted people. Also, we collected important data about their performance when reading through vibration, but this time with a glove. In the same user study, we tested the performance when writing using the buttons installed in the gloves. We also collected information about what they think about using this type of devices.

Regarding the evaluation made, our tests revealed, that the perception of the vibrations needs to be refined. There are some literatures that may help solving this problem. The results on writing were encouraging; in this phase, we assess that users must be trained beforehand, and that some experience with the device may be needed. Beyond that, the elicitation study revealed that blind people prefer simpler gestures, opposing the preference for more complex ones by sighted people. The performance test showed that a personalized training set for the recognizer is much more accrued than the others: the population and global trainings.

6.1 Problems

The system as presented has some issues that we need to overcome in future work. For example, the vibration damping has to be addressed, since some users reported that sometimes they do not know which finger vibrated, for example, if it was the index finger or the middle finger that vibrated. Another problem reported is that sometimes the buttons do not work as they should, sometimes a user click on them and they do not assume the contact. In the second user test the recognition results were not as high as expected due to some rotations that the accelerometer did not detect.

6.2 Future Work

A few problems must be solved to improve the design development, and knowledge about the problematic of touch screens for blind people. These problems suggest a variety of research directions that need to be pursued in order to make such systems usable by blind people:

- It is necessary to expand our knowledge about how blind people think of the application of braille in new technologies, and how they see the usage of wearable devices in public. Due to the small size of our sample, it is necessary to get a bigger picture performing a large-scale study to address these issues.
- Improve the gloves design with better sensors, less wires, and no buttons.
  - If the accelerometer sensor get upgraded, the recognition results may also improve leading to better recognition rates.
  - Connecting the Arduino through Bluetooth will reduce the intrusion due to the high number of wires.
  - Getting a smaller Arduino, or even a costume made PCB (printed circuit board) will reduce the size of the board and at, the same time, allow to placing the board inside the gloves.
  - Replacing the buttons with pressure sensors will improve usability of the writing recognition.
- Use input method from Android API, will allow blind people to use the interface for text writing and reading, system wide.

With the exponential growth of wearable market and the effort that the academic community is putting into the accessibility technologies, assistive technology systems still have a large margin for improvement. With all of that, it is expected that assistive wearable devices will play an important role in the social integration of people with disability, creating a more equal and just society.

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